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DEEP FRIO SAND IN OLD OCEAN FIELD MATAGORDA COUNTY, TEXAS

14

Mud (Caustic, Quebracho):
R_m = .55 @ B.H.T.
Bit Size: 8¾"
Spacings: AM = 16"
AM' = 64"
AO = 18' 8"

LOG ANALYSIS

1) Water saturation S

R_t = 8.5 ohms

Departure curves are necessary to establish the value of R_t in the sand from 10,128' to 41' because of bed thickness.

R_o = 1.2 ohms in adjacent wells where the sand is below water level.

$$S = \sqrt{\frac{1.2}{8.5}} = 38\%$$

2) Formation water resistivity R_w

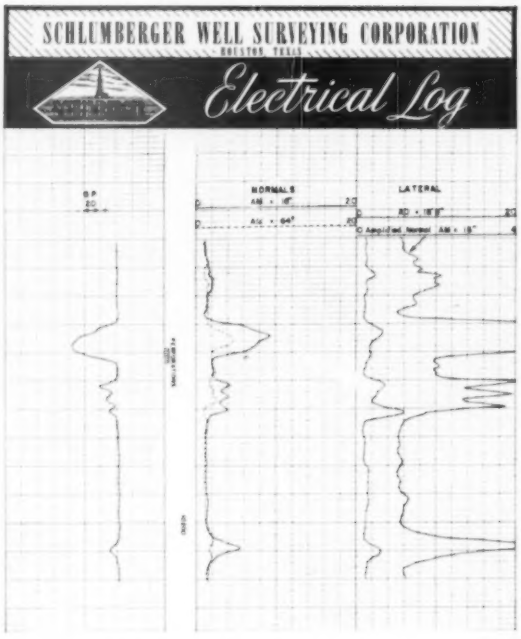
with $SP = -70 \log_{10} \frac{R_m}{R_w} = -60$ mv.,

R_w = .076 ohms @ B.H.T.

3) Porosity p

$$F = \frac{R_o}{R_w} = \frac{1.2}{.076} = 16$$

$$p = \sqrt[m]{\frac{1}{F}} = 21.5\% \quad \text{for } m = 1.8$$



CORE ANALYSIS

Average Porosity	24.3%
Average Permeability	248 md.
Residual Water	48.7%
Residual Oil	11.1%
Total Fluids	59.8%
Connate Water	37%

PRODUCTION RESULTS

Production Section:	10138 – 43'
Production Potential:	194.5 BOPD 37° API
Gas/oil ratio:	1141/1
Water:	25.1%

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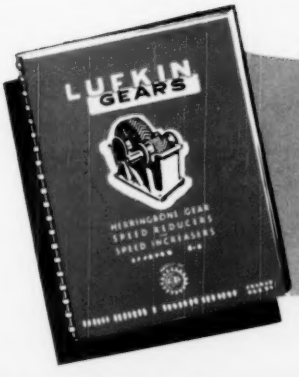

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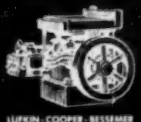

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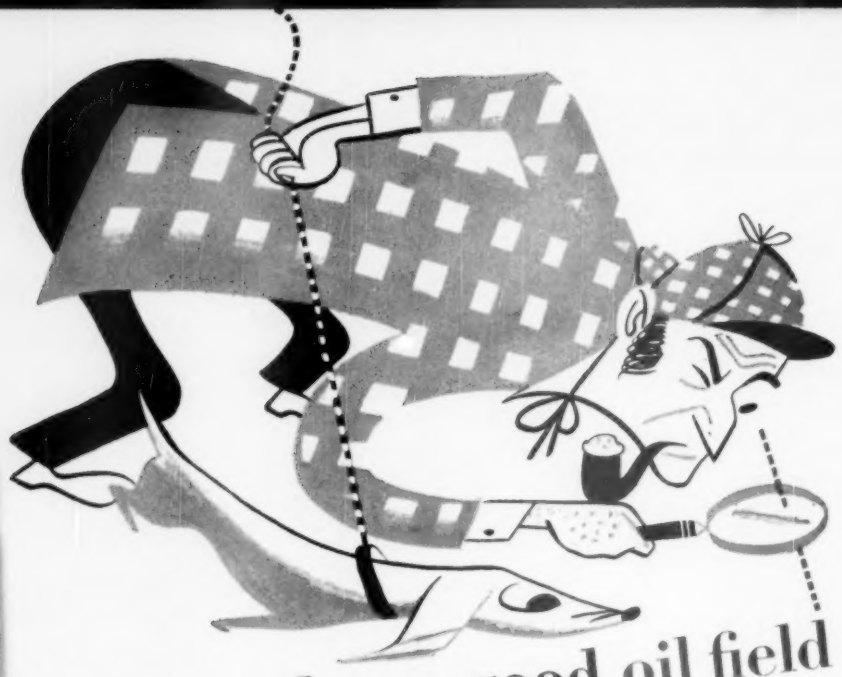

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Editorial Comment —

THE TECHNICAL MAN'S ROLE AS INTERPRETER

By E. F. Bullard
President, Stanolind Oil and Gas Co.

FOR a generation, our nation has been in the midst of the greatest technological revolution the world has ever seen. The immense industrial machine that we have built has largely been the work of our technial men — our engineers, chemists, physicists, scientists. Working as a team with the investor and financier, the result has been the highest standard of living ever achieved by man.

The evidence of our society's abundance is all about us. Yet in spite of this overwhelming evidence, the economic system which has made it possible is under serious attack. Charges are made that big business is monopolistic, that corporations make too much profit, that business is squeezing the consumer by setting prices that are too high. Though these charges and others like them lack factual basis, continued attrition can have only one result — permanent injury to the system which has made our abundance possible.

Whatever the causes for the dilemma in which free enterprise finds itself, it is an unpleasant fact that the American public has many misconceptions about our economic system. This fact has given rise to the frequent statement that we are a nation of "economic illiterates."

Among the more widely held misconceptions about business is the belief that industry is making excessive profits. According to authoritative studies of public opinion the average person guesses that industry makes 25 per cent profit, but indicates he considers 10 per cent to be a "fair" return. As a matter of record, the U. S. Department of Commerce reports that industry has made an average of 6.2 per cent in the last two years, and about 5 per cent over the previous 10-year period.

Also widespread is the feeling that "prices are too high." Reflecting this opinion is the recent Congressional approval of an investigation of gasoline prices. The petroleum industry well knows that the overall trend of gasoline prices through the last 30 years has been downward while gasoline taxes have risen spectacularly. Nevertheless, the misconception about unnaturally high gasoline persists.

THE only conclusion that can be drawn from many such examples is that the public as a whole does not understand how our system operates; nor does it know what economic and social conditions are necessary to keep the system in good running order. Mistaken beliefs such as the public holds can exist only in an atmosphere of misinformation or no information at all. As Harold E. Stassen stated recently, capitalism "is the most undersold economic system in all history."

It seems apparent that one of the most important jobs industry faces today involves neither a technical nor a financial problem. The problem is, instead, a social one. We must interpret business to the public. We must see that the public gets and understands the principles and facts about free enterprise.

I know of no more logical person to do this job of interpretation than the technical man. He knows the problems. He should be one of the best equipped to gauge the impact of his technologies on society. As a responsible architect of our mass production system, he must also accept the companion responsibility of interpreting his work to those outside his profession.

Unfortunately, our engineers and scientists have not always accepted this responsibility. One of the important factors in the nation's "economic illiteracy" is undoubtedly the fact that technical men have left to someone else the interpretation of the system they have helped to create. Too large a number have been satisfied to stay within the narrow confines of their own world of the slide rule, drafting board, and laboratory.

The consequences of narrow technicalism are all too plain. Pre-war Germany, for instance, was technologically one of the most advanced nations in the world. But its scientists and chemists and engineers chose an ostrich-like attitude when it came to community, national and world affairs. Dr. Penrose S. Albright, head of the department of physics at the University of Wichita, contacted many German scientists during the rise of the Nazi party. He quoted many in the almost identical statement, "Politics is a dirty business; I have nothing to do with politics; I leave that to the politicians."

WHETHER our nation would, even in extremity, follow a course similar to that of Nazi Germany is something that cannot be answered. It is strongly doubtful. However, the warning is there, and we should heed it.

To take his active part as a citizen in community and national affairs, the technical man should be skilled, not only in his own field, but should be equipped to understand the social implications of his work. He should make it his duty to know and analyze the weaknesses and strengths of business, and to offer constructive improvements if they are necessary. This means he should know the function of capital investment, the role of profits, the part competition plays. Furthermore, he should be able to express himself clearly, either in writing or in speech, so that any person with a minimum education can understand him.

Unfortunately, few of our technical men have such a background or training. While the trend in some progressive schools is away from excessive specialization, our college curricula still offer the technical student too little opportunity to broaden himself. Therefore, the technical man must take it upon himself to broaden his knowledge in such subjects as history, economics, sociology, political science and philosophy. Certainly he needs this broad background in order to properly apply or understand the effect of his technology.

The time is now long overdue for the technical man to be as clear in his economic and social thinking as he is in his interpretation of science.

He must first understand the system. He must make up his mind about the many urgent problems facing the country today. Finally, he must be active in support of his beliefs, whatever they may be. To deserve the respect which the public accords him, he cannot in good conscience do otherwise. ★

MUD FLOW THROUGH OIL FIELD DIAMOND CORE BITS

By Burton J. Westman

Koebel Diamond Tool Co.

SIGNS of erosion are easily apparent when examining bits in use, and it is sometimes possible to alter the fluid volume enough to arrest further erosion without affecting the condition of the hole. If this is not possible subsequent bits must have provisions made for a greater volume of fluid, but care must be taken in altering the fluid passages, because the tendency then is for most of the fluid to go through the larger passages instead of around the diamonds. This increases the danger of burning; it also prevents the cuttings from being ejected efficiently, which, in turn, decreases both the penetration speed and the life of the bit.

This excerpt was taken from an article entitled: "How to Use Diamond Bits in Deep Drilling," prepared under the auspices of the Toolmakers' and Research Committee of the Industrial Diamond Association of America, Inc., and was published in *The Petroleum Engineer*, September, 1948. The general subject of this paper may seem to sharply digress from that statement but it is the result of extensive research into fluid erosion of oil field diamond core bits during the past seven months that has brought about much evidence which weighs against the general theory contained in the foregoing excerpt. Some of the fundamentals contained herein point toward a new concept regarding core bit designs, particularly the fluid capacity of a given core bit. Most of the evidence is based on extensive field results and detailed examinations of worn core bits. The results have added to the momentum of the investigation into new core bit designs to permit high mud volume without excessive velocity across the face of the bit in order to reduce the bit bounce and diamond damage.

Oil field core bit designs have been numerous and many were apparently more effective in appearance than performance. The main object is to present sufficient diamond points so arranged as to cover each other in rotation and create an equal scraping action on the rock surface. In that each diamond acts as a small drag, a diamond bit can be considered a multiple drag bit with adequate spacing of fluid channels to remove the rock fragments sheared from the formation being cut and to appropriately dissipate the high frictional heat that is generated during the cutting action.

Plain water has long been accepted as the best diamond coolant but in oil field practice, however, the drilling fluid has to serve several functions therefore properly compounded muds are used. But generally the required mud volume circulated is usually much greater than is necessary to flush a given diamond bit. Oftentimes the high volume required in many deep wells precluded diamond coring as usually practiced due to low capacity bits that were designed to pass a mud volume $\frac{1}{3}$ to $\frac{1}{5}$ the well requirements. High mud volume therefore is necessary but to exceed the core head capacity results in bit bounce that is very damaging to the diamonds. This bit bounce is possibly due to a piston effect of the core in the core head combined with harmonic pipe shortening resulting from pump surge, all of which tends to pick up the bit and drop it again in a more or less rhythmical fashion. This sharp variance in bit loads results in the individual diamonds' alternating between no contact with the rock to a sharp overload which creates the shock that damages the diamonds, especially those in the crown which cut directly into the rock and least to the others toward the gauge in proportion to the reaming angle relief.

This article was submitted for publication and received in the office of the Petroleum Branch December 6, 1949.

Early Bits Failed

Early diamond bits invariably failed along the crown where the wear was not attributable to junk damage. This problem was overcome by packing in more diamonds into the bit crown to lower the unit shock per diamond point but this was done at the expense of proper fluid clearance and resulted in a still higher mud velocity across the bit crown. This higher mud velocity increased the matrix erosion and, due to the reduced mud channel sizes, the probability of junk damage to the crown increased proportionately in that fragments could not be circulated past the bit. It seemed logical therefore that a reverse of this trend would be more practical for the existing conditions; to increase the mud capacity thereby reduce the bit bounce would keep a bit containing fewer diamonds constantly and more efficiently in contact with the rock.

The latter was attained some time ago by the Electro Drill Corp. which uses the standard $6\frac{1}{8}$-in. by $3\frac{3}{4}$-in. insert-type core bit.[1] The number of inserts in these bits during the past two years were gradually reduced from 20, containing approximately 250 carats of diamonds, to ten, containing less than 150 carats, down to eight inserts containing about 100 carats. The results were surprising. Less diamonds gave greater efficiency in penetration speed, lower footage costs, and greater bit economy. The striking point about the worn bits is that the crown and the inside gauge diamonds had little or no noticeable wear after hundreds of feet of coring and reconditioning was required only because of damaged outside gauge diamonds which resulted from many hundred-thousand accumulated trip feet. Mud erosion of the matrix, rock abrasion or junk damage has been nil so that the bit blanks are reset a number of times at a considerable saving.

It is believed that the great increase in mud capacity of these bits containing so few inserts bounded by wide mud channels coupled with constant uniform contact of the bit against the rock are responsible for this coring efficiency.

With this in mind, experimentation started in 1948 with higher mud volumes in Louisiana where maximum mud circulation is often absolutely essential. This research into bit deficiency resulted in a "port bit" wherein a series of tapered holes were bored from each channel just outside the crown center into the bit taper just above the major constriction at the inside gauge. The first bit of this type was an $8\frac{3}{4}$-in. standard insert bit run by the author early in 1949. Subsequent bit performances with this design, particularly in the

Arkansas-Louisiana-Texas area, has shown that this higher circulation capacity eliminated bit bounce, increased penetration rates, and prolonged bit life with attending decrease in diamond consumption. The resulting increase in fluid area eliminated the usual terrific velocities between the core and the inner bit gauge where but a minimum of mud is required and diverted the fluid to an area where it is most needed. It now appears that a better fluid efficiency seems to be below 2,500 ft per minute across the bit crown; below this velocity even soft matrix has little or no tendency to erode. Fluid velocities upwards of 6,000 ft per minute have a marked effect on matrix erosion and diamond damage due to bit bounce. Increasing the fluid area and the fluid capacity yet maintaining a low velocity past the bit crown affects the penetration rate in all formations, especially shales. Jetting action of the ports also keeps the cutting face clean and it is believed that this action in shale accounts for the more rapid penetration. Ten to 20 minutes per foot in shale is often common apparently due to elimination of balling or slicking of the core bit crown.

Channel Spacing

The most noticeable effect of diverting almost all of the mud through deep, closely spaced channels is the sharply reduced rock abrasion and fluid erosion of the matrix around the diamonds. Probably the reason for this is that, due to closely spaced channels, the solid content or cuttings in the mud that traverse the diamond studded matrix is reduced to a minimum and thus can be ejected efficiently. The very high pressure drop along those divisions of the crown between the channels causes the mud to flow in a path opposite the direction of rotation. A short traverse to prevent packing of cuttings between the diamonds and the attending matrix abrasion therefore is essential. In the field, the faster penetration rates obtained in almost every formation have shown that deep, closely spaced channels have brought about very efficient "sludging" or flushing of the bit crown. In addition, during this period, only one bit was burned out and that resulted from inadequate circulation due to pump failure.

The penetration rate, of course, in any formation also depends upon two important factors: proper bit weight and rotational speed. High rotational speed with heavy oil field rotary equipment is probably impractical due to excessive vibrations that develop which are exceedingly damaging to the outside gauge diamonds. Proper bit weight is usually difficult to maintain in sedimentary rocks of ever-changing physical characteristics. Diamonds penetrate by being pressed into the rock but, on rotation, the rock's resistance to shear opposes the bit weight so that for any given rock the actual bit weight is dependent upon the shear strength of that rock plus the speed of rotation. This, of course, does not consider the force required to oppose the pick-up action of the drilling mud and other mechanical factors. High bit weights can, in a soft, low-strength, abrasive rock, result in packing and excessive rock abrasion of the matrix between the diamonds, especially toward the trailing areas of a crown that has small or widely spaced mud channels. Frequently, hard formation bits without adequate or closely spaced radial channels, on encountering an inter-formational shale parting, core very slowly and, if continued, either burn out the crown or its stones shatter on sudden cooling. Occasionally cracking and sometimes separation of the crown matrix takes place.

Under normal operating conditions, diamond wear should be nil. Due to its abrasion resistance and indentation hardness over any other substance,[2] the only wear should be polishing which probably results from high frictional skin heat and subsequent microscopic spalling plus oxidation on the edges of the diamonds which are in contact with the rock along which the coolant cannot reach. The rate of wear, then, should depend upon the resistance to shear of the rock being cut. However, considerable mechanical wear on diamonds is due to washing down over cuttings, core left on bottom and, more often, due to excessive bit bounce which is evidenced in softer rocks by fluted or spiraled cores. Mechanical wear also results from cutting through broken rock or very heterogeneous formations and, to some extent, regrinding cuttings and abrasive solids in the mud.

High-Clearance Bits

Coring with high clearance bits has shown that diamond wear can be minimized along the crown and inside gauge. The little mechanical damage to the outer gauge diamonds due to trips will continue but this damage in recent months has been nil. Another important function of high-clearance bits is to circulate out rather large pieces of junk, cuttings, and cavings that have wrecked many bits in the past. Although operators have become very "junk conscious" and have learned to clean up a hole prior to coring very thoroughly, infrequent junk damage to the bits continues due to junk that occasionally dislodges from the walls between coring trips. To prevent this occurrence, a multiple pole magnetic junk retriever plug is being developed to pick up junk which cannot be circulated out past the bit. It is a "rabbit" which is to protrude beyond the bit and pick up junk during the pre-coring circulation, then ride above the core up into the inner barrel. This plug is removed for cleaning when the core barrel is emptied. This plug, however, is intended only for the very large junk and not the smaller fragments such as rock bit teeth and cone bearings that can wash past a high clearance bit. It cannot be relied upon to trap junk which is pumped down to the bit as on one occasion where the swivel bearings broke up completely and were washed out during coring with no damage to the bit.

Another apparent function of the high clearance bit is to wash out core fragments that formerly packed in the inner taper above the bit crown. This packing or wedging action is similar to the core recovery procedure as practiced in the calyx coring method wherein large fragments of hard rock are introduced into the flow line so as to be pumped down and become wedged between the core and the core bit to effect recovery when coming off bottom. This wedging action has further complications in that it tends to break up the core being cut and often is directly responsible for core jamming. Oftentimes these fragments temporarily lock the core to the head to cause erratic pipe torque which drops to normal when the fragments are crushed small enough to wash out past the bit. This packing of fragments has also been known to block a number of small mud channels and cause partial burning of the bit crown. That high mud clearance tends to eliminate this packing and subsequent core jamming has been shown by the marked increase in the average footage made per trip. In areas where footage obtained per trip was rather erratic a full barrel is now expected. Other factors, however, enter the picture such as a re-designed core catcher that permits high circulation through the pin type bits and a recently developed practice of coming off bottom when coring time goes up, circulating at full pressure, then resuming coring. Many so-called "core jams" have been overcome where formerly the only alternative was to make a trip.

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* * *

LIME CONTENT OF DRILLING MUD—CALCULATION METHOD

M. D. NELSON AND **T. E. WATKINS,** MAGNOLIA PETROLEUM CO., DALLAS, TEXAS

A method of determining the lime content of drilling muds proposed by Battle and Chaney* has been examined both in the Field Research Laboratories of Magnolia Petroleum Co. and in field drilling operations. This proposed analytical method is condensed as follows: Titrate one ml of mud and one ml of mud filtrate, each with 0.02 N H_2SO_4, to the end point with phenolphthalein. The volume of acid in ml required for the mud titration is recorded as P_m and that of the mud filtrate titration as P_f. Calculation of the lb lime/bbl mud is accomplished by use of the formula,

$$\text{lb lime/bbl mud} = 0.6\ (P_m - 1.3P_f) - 0.6$$

The analytical procedure outlined by Battle and Chaney was found to be quite satisfactory when reasonable precautions are used in mud sampling technique. Calculation of lime concentration by the method proposed in the above publication, however, has given values that varied as much as 100 per cent from the known lime content, for muds of either high or low solids concentration.

By use of a formula, lb lime/bbl mud = 0.26 $(P_m - F_L P_f)$, based on chemical equivalents† of acid required for titration, both laboratory and field data have been satisfactorily correlated with the known amounts of lime present in the muds. In this formula a correction, F_L, or volume fraction of liquid in the mud, is made for the solid content of the mud. P_m and P_f have the same significance as in the Battle and Chaney equation. Table 1 shows typical data employing both formulas in calculating the lime content of various lime muds.

This suggested procedure ignores lime which is in solution in the mud. The solubility of lime in water, normally about 0.5 lb per bbl, is greatly decreased by the addition of caustic soda, and, in a lime mud, it is probable that the concentration of dissolved lime is of the order of 0.1 lb per bbl. Such an amount of lime can be ignored, since it is within the range of accuracy of the method.

A nomograph for the graphical determination of lime content by this method is shown in Fig. 1. In the construction of this nomograph, it was assumed that weighted muds contain 8 volume per cent of light solids. This value was based on the average composition of a number of lime muds. Using a value of 4.30 for the specific gravity of barite, total liquid fractions (F_L) were calculated for weighted muds up to 18 lb/gal (135 lb/ft³).

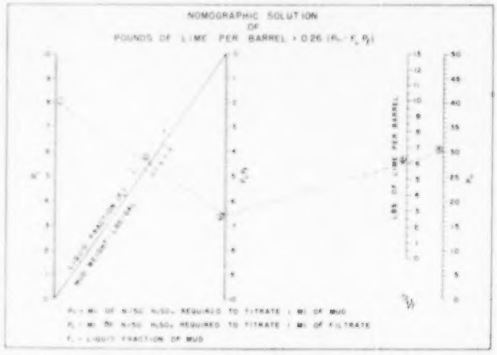

NOMOGRAPHIC SOLUTION
OF
POUNDS OF LIME PER BARREL = 0.26 (Pm - FL Pf)
LBS. OF LIME PER BARREL
Pm = ML OF N/50 H2SO4 REQUIRED TO TITRATE 1 ML OF MUD
Pf = ML OF N/50 H2SO4 REQUIRED TO TITRATE 1 ML OF FILTRATE
FL = LIQUID FRACTION OF MUD

Fig. 1 — Nomographic Solution of pounds of lime per bbl = 0.26 $(P_m - F_L P_f)$.

Employing this nomograph, results on the analysis of five muds were determined independently by five separate operators. In the 25 indicated operations, results showed a maximum deviation of 0.1 lb of lime per bbl from the value calculated by means of the equation. This degree of accuracy and reproducibility was attained by plotting the P_f and P_m titration values to the nearest 0.05 and 0.5 ml, respectively, and the mud weight to the nearest 0.5 lb/gal.

A limited number of copies of this nomograph are available and may be secured from the authors. ★ ★ ★

Table 1
Calculation of the Lime Content of Various Muds Using Two Formulae

Mud	Total Lime # /bbl	P_m Ml	P_f Ml	# Lime /bbl Mud $0.6(P_m - 1.3P_f) - 0.6$	Error # /bbl	# Lime /bbl Mud $0.26(P_m - F_L P_f)$	Error # /bbl	Mud Composition
A	1	10.65	6.10	1.04	+0.04	1.18	+0.18	Non Bentonite Lime
A	4	20.75	5.15	3.65	−0.35	4.04	+0.04	" " "
A	8	35.60	6.00	16.10	+8.10	7.66	−0.34	" " "
B	6.25	20.75	4.61	8.25	+2.0	4.26	−1.99*	Bentonite-Lime
B	10.25	34.56	4.73	13.32	+3.07	7.75	−2.50*	" "
B	12.25	41.68	4.91	20.58	+8.33	9.60	−2.65*	" "
C	4.25	17.53	6.67	4.71	+0.46	2.91	−1.34*	" "
C	6.25	24.45	6.72	8.83	+2.58	4.69	−1.56*	" "

* Error is partially due to the lime assimilated by base exchange.

* Paper on "Lime Base Muds," presented by J. L. Battle (Humble Oil and Refining Co., Houston, Tex., and P. E. Chaney (Sun Oil Co., Beaumont, Tex.), at the 1949 Spring Meeting of the Southwestern District API Division of Production, Dallas, Tex. The analytical procedure has also had wide distribution in a trade journal, *Kembreak*, published by the Accuracy Rig and Tool Co., Houston, Tex.

†Derivation of equation
lb/bbl = grams/350 ml
1 ml 0.02 N acid = 0.000741 grams of lime
1 ml 0.02 N acid/ml lime suspension = 0.26 lb of lime bbl
lb of lime/bbl = 0.26 $(P_m - F_L P_f)$

Lagniappe AWAITS THE MEMBERSHIP IN NEW ORLEANS

A PROFITABLE FALL MEETING IS PROMISED THE BRANCH AS MORE THAN 35 PAPERS ARE BEING READIED FOR PRESENTATION OCTOBER 4-6

Arriving the other day in the usual towering stack of correspondence directed daily at the Branch Office was a fat envelope postmarked from New Orleans, a municipal nomer uncommonly popular these days among members conscious of the Branch Fall Meeting to be held there October 4-6. The letter was particularly inviting because of its weight, a hold-over feeling perhaps from the days when money-from-home arrived in similar packets.

At any rate, the correspondence came in over the signature of Fred E. Simmons, Jr., chairman of the currently busy Delta Section. Fred was eager. Appended to a letter addressed to the Branch Secretary was another communique, this time addressed to the entire membership. The salutation read: "My Dear Fellow Members . . . " What followed was a colorful piece of writing expounding the virtues of the "South's Queen City" from its early plantation days to the modern, port city which it is today. Fred compared himself to a plantation slave who in the olden days was set out with "delicately penned invitations" some weeks prior to an extravagant function to scour the countryside and spread the word. He asked that we pass this along so let him continue briefly:

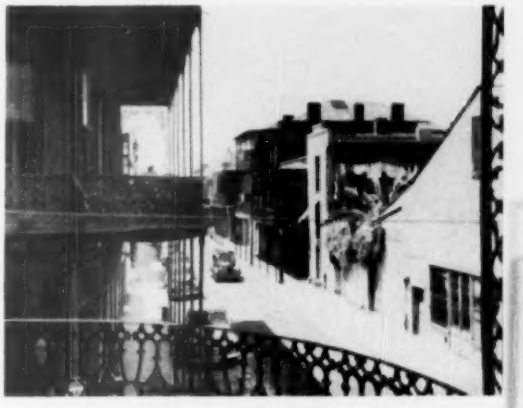
"I'm going to take the place of (that slave) and bring you all an 'invite' from the Delta Section to attend the Fall Meeting of the Petroleum Branch in New Orleans. Since I learned by readin' and ritin' I'm going to give you a little *lagniappe* (a little something extra for nothing). I'd like to tell you a little about the entertainment and New Orleans."

Fred then drifts off into quite a piece about the old city and its selling points. He writes of the efforts of E. N. Van Duzee and Aime Claudet in lining up a palatable bill of entertainment (including a "Quarter" show) . . . in order that the membership will be protected against the special brand of mickey finn concoted in the Vieux Carré. He goes into great detail about "side trips" to Merida, Yucatan, Mexico via airways for a study of the Mayan ruins and excursions to Havana, Honduras, the Gulf Coast of Mississippi, Florida, etc. These attractions he offers, happily, as post-meeting attractions not to interfere with the all-important technical sessions.

A large number of hotel rooms has been set aside for Petroleum Branch members planning to attend the Branch Fall Meeting in New Orleans. However, in order to be certain of getting a reservation, you should make your request for one now. Blanks were provided in the March issue of PETROLEUM TECHNOLOGY. If you still have them, use them. If not, mail your reservations to H. E. Lowrey, chairman of the Housing Committee, 519 Whitney Bldg., New Orleans 12, La.

In your letter (or on the prepared form referred to above) state your choice of twin or double room, approximate time of arrival and departure in New Orleans, your choice of three hotels and your name and address.

You may choose from the following hotels: Roosevelt (headquarters), St. Charles, De Soto, Monteleone, Lafayette, New Orleans and Jung. Remember, dates of the Fall Meeting are October 4-6. Avoid congestion. Be sure of your reservation. Mail it in now.



For the more unpredictable governing factors for a successful meeting, Fred went to a common source. He continues:

"My *Grier's Almanac* says that Mars will be in conjunction with the moon on October 4, that we can expect thunder storms on October 5; and that the Mormons ceased polygamy on October 6, 1890. I expect that the most important thing to note here is that the weather should be pretty good about the time our Fall Meeting will be underway, even though we can always expect rain. In any event, you will probably find summer or very light fall clothing will afford you the most comfort during October."

Fred continued with a list of sights to be seen in New Orleans proper, such as Chalmette, the Napoleon House, Lafitte's blacksmith shop and the variety of architecture dating the different districts of the city. Delta Section members claim that a person can begin in the Vieux Carré, move up St. Charles Ave. and follow the stages of New Orleans growth by the changes in architecture.

Fred ends his communique with the idea that there will be a "time of general rejoicing" when the membership convenes in New Orleans this Fall just as there was during special occasions in olden days. All of which calls for a note of thanks to the Delta Section for its hearty work in preparation for the Branch Fall Meeting. Meanwhile, a strong agenda of technical papers is being prepared and approved for delivery. Some 35 papers, 12 of which have already been accepted, are being studied for pre entation. Everything points to an even more successful and fruitful meeting than was held last year in San Antonio. ★ ★ ★

the Editor

Well Spacing and Water Flooding

By Milan G. Arthur

The second lecture of the current AIME series on secondary recovery was given by S. T. Yuster of UCLA May 22, at the General Petroleum auditorium in Los Angeles. Yuster continued his discussion of secondary recovery which he had commenced at the meeting held in April. The principal subjects discussed were well spacing and some of the critical problems encountered in water flooding.

With regard to well spacing, the factors presented were development costs, operating costs, and recovery time, which factors are controlled by pressure, permeability viscosity of fluids, effective well radius, recovery per acre, and pressure gradients within the reservoir. Yuster presented a formula for break-even spacing, which was defined as that well spacing which would result in complete return of the cost of the water flooding project but would yield no profit. An analysis of this type of spacing is valuable in evaluating the susceptibility of a given oil field to water flooding. Well spacing was also considered as a function of the time to complete the flooding project. The development costs included those of new wells, of rehabilitating old wells, and of converting producing wells to injection wells. Operating costs included the cost of producing, treating, and pressuring water for injection and lifting costs.

In this regard, it has been found that, although the amount of water required over the life of the flood varies greatly in different fields, an average of 15 bbl of water injected to each bbl of oil recovered over the life of the flooding project is a reasonable estimate. Lifting costs are a function of volume of fluid to be pumped and depth from which it must be lifted. Experience in various fields indicates that an average of 9 bbl of water produced for each bbl of oil recovered is a reasonable estimate, but this factor may also vary widely. In determining spacing, all contributing factors are expressed in terms of spacing and the resulting equation is solved for the distance between injection wells. In practice, a pre-determined life of the project is often selected and the spacing equation is then solved for the spacing necessary to complete the project in the prescribed time.

With regard to important problems encountered in water flooding, Yuster discussed the effects on oil recovery of pressure gradients, anisotropy of the sands, injection of gas prior to water flooding, use of surface active agents in the injection water to increase recovery, high oil viscosity, and heterogeneity of the reservoir permeability.

With regard to the effect of pressure gradients, Yuster considered first a theoretical analysis of the rate of movements of fluids in capillaries of different diameters. By substitution of the force developed by capillarity in Poiseuille's formula for flow in capillary tubes, it was demonstrated that the velocity of movement of fluid under capillary forces is proportional to the diameter of the capillaries, and that the velocity is not greater in smaller capillaries as is frequently presumed. This would indicate that recovery in dynamically water wet sands would not be increased by employing pressure gradients low enough to be within the range of capillary pressures. Some laboratory investigations were discussed in which it was found, for the particular system studied, that there was little change in ultimate recovery of oil with change in pressure gradients, but at higher pressure gradients earlier initial production of water commenced.

Therefore, it would seem that excessively high pressures would result in an early increase in water out of the producing wells and an increase in cost of operation. With regard to field experience, it was pointed out that some sands which have been subjected to exceedingly slow infiltration of water have attained a condition described as water logging, wherein the oil saturation is quite high but the sands have not been satisfactorily flooded. It is believed that the reason for failure of attempts to flood such sands is due to the fact that the continuity of the oil phase has been broken by the infiltration of water at capillary rates. Therefore, it would seem that there is some practical lower limit to pressure gradients employed.

Anisotropy of the sand, which is the variation of permeability in different direction in the sand, can often be expected. If this condition can be evaluated, it should be considered in determination of the well spacing pattern, so that water from various injection wells will reach the producing wells at the same time and therefore achieve the highest sweep efficiency.

The practice of injection of gas prior to commencing water injection was discussed. It was presumed that where oil is the non-wetting phase, then injection

PRE-MEETING DISCUSSION at the Pacific Technology Group's recent dinner finds, L to R, Hugh W. McClellan, Wayne E. Glenn, R. M. Smith, Paul Hamann, all of Continental Oil Co., and Randolph Smith of Seaboard Oil Co. exchanging viewpoints.

of another non-wetting phase, such as gas, will increase the recovery of the oil. It can be anticipated that the maximum amount of additional oil recovered will be equal to the volume occupied by the gas at equilibrium saturation. Equilibrium saturation is that below which the gas will not flow through the sand. The existence of gas saturation may greatly increase the recovery of oil over that recovery where free gas is not present.

The use of surface active agents has frequently been considered. In general, it has been found that they are very effective in increasing recovery of oil but that their cost makes the use of them prohibitive. A promising possibility in this regard is the use of some low cost chemicals which react with constituents of the crude oil and thereby reduce interfacial tension between the fluids and increase recovery. One of the important problems is to prevent such chemicals from being absorbed on the mineral surfaces and thereby prevented from reacting at the location of the oil-water interface. A most promising possibility would be the injection of certain cheap residue gases which might react with constituents of the oil to achieve the desired results. Since these gases would be a non-wetting phase, they could probably be dispersed through the reservoir without absorption on the mineral surfaces.

The problem of water flooding high viscosity oil was discussed and some of the practices considered were the injection of solvents to reduce viscosity and the injection of hot water obtained from deeper water bearing horizons to reduce viscosity.

The problem of heterogeneous permeability is generally solved by selective plugging, corrective shooting in sands which are susceptible to shattering, delayed drilling, and isolation of certain sand intervals by multiple and selective completions. With regard to corrective shooting in sands that do not normally respond satisfactorily to such treatment, the possibility was suggested of first consolidating these sands with some material such as plastic and subsequently shooting with nitroglycerin to increase the effective well radius. An increase in effective well radius permits wider well spacing and reduction of costs.

In conclusion, C. R. Dodson, chairman of this lecture series, announced that the next lecture was to be given on June 26. At that time, R. V. Hughes of the Stanford Research Institute was to discuss phases of secondary recovery including the effects of clays occurring in the oil sands, pore size distributions, and the application of laboratory investigations to field performance. ★ ★

NORTH TEXAS SECTION

Geophysical Prospecting for Oil

By Kenneth F. Anderson

Frank Mortlock, geophysical supervisor of the West Texas Division of Gulf Research and Development Co., discussed the general theories involved in geophysical prospecting for oil-bearing structures before a group of some 40 members and visitors at the North Texas Section's May meeting in Fort Worth.

Herb A. Koch introduced Mortlock, and a summary of his talk follows.

The geophysist, as the name implies, is a person who applies the science of geology and physics. In doing this the geophysist measures any of the earth's physical properties available at or near the surface of the ground and attempts to interpret these findings in a way that knowledge may be gained of the formations at greater depths. The physical measurements ordinarily made are hydrocarbon gas content of surface waters and soils, the earth's magnetic field, the earth's gravitational field, the electrical conductivity and resistivity of the surface rocks, and the elastic properties of the underlying sedimentary rocks. The measuring of these quantities and the interpreting of their meaning is geophysics.

When prospecting for oil, the geophysist endeavors to locate anticlines, salt domes, faults, and stratographic traps. To accomplish this, most oil companies make use of three principal methods of geophysics; magnetic, gravity, and seismograph. The magnetic and gravity methods are used for general reconnaissance work because large areas can be covered quickly and cheaply by these methods. The seismograph is used for more detailed investigations and is divided into two types: reflection and refraction.

The magnetic method is quite old and was first used in the mining industry. This method of geophysics is based upon differences occurring in the earth's magnetic fields. The gravity method which has been in use for about 28 years was the first geophysical method to be used successfully in the location of oil fields. The first great success using this method was accomplished in the Louisiana-Gulf Coast area employing a so-called torsion-balance of German design. The seismograph utilizes an artificially produced earthquake and measures the time required for the energy to reach receptors or geophones placed at regular intervals from the explosion by either a reflected or refracted path. Although the refraction method was first developed in 1913, it was not used successfully by the petroleum industry until 1925. This first success was made locating salt domes in the Gulf Coast area. In 1928, three years after the successful use of the refraction method, the reflection technique was developed. In most instances, the reflection method is faster, less expensive, and gives more information. Consequently, at this time the refraction method is used only in areas that do not lend themselves to the reflection technique.

Mortlock stated that the ideal procedure is to make an airborne magnetic survey of a large virgin area, followed by a gravity survey of the most interesting anomaly, and lastly, to go into the selected areas with the most detailed tool, the seismograph. Using this method, if the conditions are right, it is possible to determine with a fair degree of accuracy the folding and warping of the sedimentary rocks. At best, however, the probable error may be somewhere between 25 and 50 ft.

Today, some 25 years after geophysical methods of prospecting were introduced to the oil industry, there are very few wildcat wells located without the use of some form of geophysics. Geophysics is practiced all over the world, spending perhaps $100,000,000 a year on a continental search for the rich sources of the petroleum industry. ★

TECHNICAL CONFERENCE

West Coast Students and Industrymen Present Papers at Joint Meeting

By Paul Newton

The AIME student section at the University of Southern California initiated last month a technical conference, held in Founder's Hall, the university's newest building. The conference was designed so that graduate and undergraduate students from various universities and colleges might have an opportunity to present papers to be judged by prominent men from the industry.

In addition, invitations were extended and accepted by men in industry to be guests of the chapter at the meeting. Four of the guests presented papers of their own. The meeting was divided into three sessions. The morning session devoted to the presentation of selected student papers, was presided over by Sam T. Yuster, from UCLA's department of petroleum engineering. Subject matter for these papers was limited to the fields of geology, metallurgy, and petroleum technology. The following student papers were presented:

"The Concept of Dilatancy in Geology," by David G. Moore, USC.

"Characteristics of an Unconsolidated Sand Adjacent to a Perforated Liner," by Barry L. Evans and Charles Downey, USC.

"Temper Brittle Fractures," by H. R. Grant, graduate student, USC.

"Salt Marshes and their Possible Reclamation at Newport Bay, California," by Robert E. Stevenson, USC.

"Influence of Low Temperature Cooling Rates Following Welding or Ductility or Arc Welds in Mild Steel," by Gordon McGuire, UCLA.

"Some Studies of Multiphase Relative Permeability in Consolidated California Oil Sands," by A. McKenzie Laurie and Harrison L. Staub, graduate students, USC.

"A Study of the Properties of Drilling Fluids Containing Certain Natural Organic Colloids of Iranian Origin" by George Tchillingarian, graduate student, USC.

In the afternoon of May 19, under the chairmanship of N. van Wingen, consultant of Pasadena, four of the guest speakers read their papers. Manuel Mayuga, geologist for the Long Beach Harbor Dept., spoke on the "Geology and Recent Developments in the Wilmington Field." Somewhat limited by time, Mayuga was able to paint a broad picture of the Wilmington area aided by slides. Following Mayuga, Herman E. Shaller of the McCollough Tool Co., addressed the meeting. His paper was entitled "Recent Developments in Fishing Tools." A "Review of Gun Perforating Methods," by Val L. Forsythe of the Lane-Wells Co., was the next paper read. Forsythe evaluated the advantages and disadvantages of the two most widely used methods of perforation. To conclude the afternoon session, John E. Sherborne, Branch Chairman, spoke to the meeting on "Industry's Requirements of an Engineer." Chairman Sherborne's discussion covered a problem which confronts all engineering students. Should one specialize, or work for a broad basic background while in school?

To climax the day's events, an award banquet was held in the evening, presided over by Charles R. Dodson, professor of petroleum engineering at USC. The dinner was held in the Rodger Young Auditorium, Los Angeles.

The prime function of the banquet was to present awards to the winners of the various student contest classifications. Prizes included six-inch slide rules, a copy of Morris Muskat's *Physical Principles of Oil Production* and copies of AIME *Transactions*. Awards were made to H. R. Grant, winner of the Graduate Division in Metallurgy, R. Stevenson, winner of the Graduate Division in Geology, and A. M. Laurie, H. L. Staub and George Tchillingavian, winners of the Graduate Division in Petroleum.

STUDENT MEMBERS of the University of Southern California amassed at their recent technical conference for a formal portrait. The conference was the first of its kind held on the West Coast and plans are being made to hold successive ones annually.

Undergraduate winners were David Moore, geology; Barry L. Evans and Charles Downey, petroleum; and Gordon McGuire, metallurgy. The judging committee was composed of Harold J. Clark, chief engineer for Conservation Committee of California Oil Producers, Paul Andrews, chief production engineer for Signal Oil and Gas Co., and E. A. Galvin, chief production engineer for Western Gulf Oil Co.

Honored guest of the evening was A. C. Rubel of the Union Oil Co., who spoke on "The Engineer and Society."

★ ★ ★

Benton Field Project Studied

By Julian Vallette

Shell Oil Co.'s Benton field water flood project was the scene of the Illinois Basin Chapter meeting held May 11, 1950, which consisted of a tour conducted by the company officials and an evening panel discussion. More than 240 oil men from Indiana, Kentucky, Kansas, Oklahoma, Texas, and Illinois attended the meeting. One group consisted of advance petroleum engineering students and members of the faculty from the Missouri School of Mines and Metallurgy at Rolla.

The operation of the Benton project, which was put into service in November, 1949, was explained by engineers and operators at each major installation and was demonstrated by small scale models and displays on the various phases of water treating, water injection, and return fluid treating. It was learned by the group that the Benton flood is a fully unitized project covering about 1,900 productive acres, with water being injected into the Tar Springs sandstone reservoir at a depth of 2,100 ft. A six-mile, eight-inch pipe line carries water for the flood from Lake Moses to a storage reservoir on the Rice lease located centrally in the field. From this point, the water passes through a treating plant and is conditioned by aeration, stabilization, and filtration, after which it is pumped under about 300 psi to the various central metering points throughout the field which serve the 84 injection wells. Fluid from the 120 producing wells in the project is returned to a central oil treating plant where the oil and water are separated, with the water being returned to the Rice lease storage reservoir. It was also learned that during the first five months of operation, approximately 4,000,000 bbl of water were injected into the Tar Springs reservoir.

Following a dinner at the Twin Oaks Club on Lake Benton, a panel discussion of various water floods in operation in the Basin was conducted. Members of the panel were: Robert Dunn, Magnolia Petroleum Co., Salem, Ill.; Worden W. Parrish, Pure Oil Co., Olney, Ill.; M. H. Flood, Ohio Oil Co., Terre Haute, Ind.; W. H. Roe, Superior Oil Co., Crossville, Ill.; J. R. Vaughan, Jr., Sun Oil Co., Evansville, Ind.; and Hugh S. Barger, Sohio Petroleum Co., Oklahoma City, Okla. Charles V. Cameron, Division Exploitation Engineer, Shell Oil Co., Centralia, Ill., presided. Each engineer outlined a flooding project operated by his company and a beneficial exchange of ideas resulted.

At the group's June meeting in St. Louis, Lloyd E. Elkins of Stanolind Oil and Gas Co. delivered his talk on reservoir engineering in "pumper's language." Also present at the St. Louis meeting was Branch Executive Secretary Joe B. Alford who outlined briefly the functions and purposes of the AIME. ★ ★ ★

VIEW OF BENTON WATER FLOOD of the Shell Oil Co. visited by the Illinois Basin Chapter membership. At top is the water storage reservoir and at lower left is the water treating plant. At left center are the storage tanks for treated water and the injection pump station while at the lower right are the salt water skim pit, oil dehydrators and boiler plant.

API VOLUME NOW AVAILABLE

The Division of Production of the American Petroleum Institute announces the availability of the Second Edition of the book *Secondary Recovery of Oil in the United States*, of a separate printing of the Bibliography from the Second Edition, and of the Bibliography on Secondary Recovery for 1949. These publications may be ordered from the Institute's offices, 50 West 50th Street, New York, and 816 Rio Grande National Building, Dallas 2, Texas, at a price of $8.50, $1.50, and $1.00 per volume respectively.

The Secondary Recovery volume, consisting of 55 chapters on all phases of secondary recovery operations, has been prepared by the leading oil recovery authorities in the United States and is the result of more than 12 years of intensive study and investigation in which some 300 petroleum engineers and geologists have participated. The book is comprehensive in scope, and serves as a useful reference as well as a guide to the application of methods that will insure the maximum economic extraction of crude oil from underground reservoirs. The oil which can be obtained by the application of the methods described in the book represents an important supplement to the petroleum reserves of the nation. ★ ★

NEW BRANCH POLICY OF PUBLICATION

The following is the new publications policy of the Petroleum Branch. Recently approved, the new policy supercedes and disallows the previous practice of other publications in publishing up to one-third of the volume of a technical paper presented to the AIME. The new policy restricts the republishing of material presented to the Branch to a 300-word abstract.

A paper accepted for presentation at a meeting of the Petroleum Branch, AIME, or for publication in the JOURNAL OF PETROLEUM TECHNOLOGY shall be considered the property of the Petroleum Branch. Papers submitted shall be considered to be accepted until formally relinquished by the Publications Committee of the Branch.

Presentation of a paper at a meeting does not automatically guarantee publication of the paper in JOURNAL OF PETROLEUM TECHNOLOGY. Publication of an accepted paper in another periodical before it appears in JOURNAL OF PETROLEUM TECHNOLOGY will be restricted to an abstract of not more than 300 words, with no illustrations, unless the paper is specifically released to the press by the Branch Publications Committee Chairman or the Executive Secretary on his behalf.

Every effort will be made to publish papers with a minimum of delay, even to the extent of publication before presentation, if this appears desirable. If for some reason a member desires release of his paper for publication in another periodical to an extent greater than the above mentioned abstract before it is published in JOURNAL OF PETROLEUM TECHNOLOGY, or prior to the time he is notified that the Petroleum Branch does not wish to exercise its right of publication, he should submit a written statement to this effect, stating his reason and the name of the periodical in which he desires publication, to the Executive Secretary of the Petroleum Branch. Each such request will be considered by the Publications Committee on its own merits and the paper may be released by the Publications Committee if such action is justified in the opinion of that committee. Right to publish such a paper in JOURNAL OF PETROLEUM TECHNOLOGY may be retained at the option of the Committee. Publication elsewhere *after* publication in JOURNAL OF PETROLEUM TECHNOLOGY will be permitted on request, provided a proper credit is given to AIME and to JOURNAL OF PETROLEUM TECHNOLOGY. ★ ★ ★

FRENCH NOMINATED BRANCH CHAIRMAN

Richard W. French, Jr., has been nominated for the Chairmanship of the Petroleum Branch for 1951, the Nominating Committee has announced. French was selected for the nomination following the untimely death of Charles B. Carpenter of the U. S. Bureau of Mines who had previously been nominated as Chairman.

French, vice-president of Sohio Petroleum Co., in charge of production operations with headquarters in Cleveland, Ohio, is now Vice-Chairman of the Branch. He was graduated from the University of Delaware with a B.S. in mechanical engineering in 1929. Following graduation and a year with General Electric Corp., he entered the U. S. Air Corps as a flying cadet and served 14 months as a staff officer. In 1933 he joined Continental Oil Co. and was successively a roustabout, pumper, gang pusher, compressor plant oiler, gas dispatcher, meterman, compressor plant operator and field engineer. In 1939 he was made production engineer. In 1943 he became assistant manager of Continental's Production Department and in 1947 he left Continental to join Sohio as chief engineer and assistant to the vice-president. During most of his professional life he has been active in AIME and API affairs.

KANSAS SECTION

Humbolt-Chanute Observed

Some 25 members of the Kansas Section participated in a field trip through the water flooding projects of the Humboldt-Chanute oil fields, in Neosho and Allen Counties, Kan., May 24. The tour was arranged by D. B. Taliaferro, petroleum engineer of the U. S. Bureau of Mines at Bartlesville, Okla.

Also participating in the tour were some 300 members and guests of the Kansas-Oklahoma water-flood operators.

The tour included four flood projects, located in the Humboldt-Chanute field. This field includes about 15,500 productive acres, and produces from the Bartlesville sand, which is encountered at depths ranging from 700 to 900 ft.

Perhaps one of the most interesting moments of the tour was the visit of the Cox and Hamon lease, where a small pilot-type project is in operation. From the standpoint of equipment, this project has some novel features which make it a rather unique operation. The water used for injection is obtained from the Mississippi limestone at some 1,200 ft, through one well. This water is pumped directly into the input wells by a submerged electrical Reda pump, through 2½-in. plastic-lined tubing. As to the oil, it is lifted by means of Kobe hydraulic pumps. One of these pumps was removed for inspection from one of the producing wells. It was pointed out that pumping is entirely automatic and is not affected when the wells are under water. This happens rather frequently, as the lease is on river bottom lands, which occasionally become flooded to a depth of 20 ft. ★ ★ ★

CORRECTION

Rupert C. Craze was misquoted in a May report of his talk before a meeting of the Permian Basin Section. An excerpt on Page 22, Section 1 should have read: "The volumetric balance and unsteady state radial flow equation, the fluid displacement equation, use of electrical analogue devices, and other analytical techniques to study the behavior of limestone fields appear fundamentally applicable but *do* require thorough understanding of the properties of the formation, of the fluids, their behavior during flow, and adequate production operating data."

DISCUSSION OF THIS AND ALL FOLLOWING TECHNICAL PAPERS IS INVITED
Discussion in writing (3 copies) may be sent to the Editor, *Journal of Petroleum Technology*, 601 Continental Building, Dallas 1, Texas, and will be considered for publication in the Transactions volume *Petroleum Development and Technology*. Discussion will close December 1, 1950. Any discussion offered thereafter should be in the form of a new paper.

IMPROVEMENTS IN THE X-RAY SATURATION TECHNIQUE OF STUDYING FLUID FLOW

F. MORGAN, J. M. McDOWELL AND **E. C. DOTY,** GULF RESEARCH AND DEVELOPMENT CO., PITTSBURGH, PENNSYLVANIA

ABSTRACT

Improvements in the X-ray method of measuring liquid saturation and saturation distribution are presented. Two identical direct current amplifiers have been added to measure continuously the intensities of the X-ray tube output and the beam which has passed through the core under test. The ratio of these intensities is automatically recorded on a modified Brown Electronik Recorder. Arrangements have been made to drive the core automatically and in synchronism with the recorder chart so as to give a continuous curve showing the variation of liquid saturation along the length of the core. By determining the ratio of the two X-ray beam intensities simultaneously the measurements are made essentially independent of small fluctuation in voltage and current supplied to the tube. This improved technique has been used for investigating the fluid distribution along the length of cores and core assemblies when one fluid is displaced by another. Typical results of these studies are shown.

INTRODUCTION

In a previous publication[1] a method was described for measuring the oil saturation in cores which was based on the absorption of X-rays by the fluid content of the core. While that technique is capable of yielding accurate results, the original apparatus was not especially convenient for determining the fluid distribution along the length of a core. This was primarily due to the slow response of the amplifier and galvanometer and the necessity of making a point by point survey of the material under investigation. It was, therefore, not only possible for sections of the core having a variable or unusual saturation distribution to escape observation entirely, but changes in output of the X-ray generator between readings on the unknown and the monitor introduced errors in the measurements that could be avoided only by further stabilization of the source or by taking a large number of readings.

This paper describes a method and apparatus for recording continuously and automatically the intensity of the X-ray beam that is transmitted by a core. The variation of saturation with time at a given section of the core may thus be found, or by scanning the core by driving it in synchronism with the recorder the saturation distribution may readily be determined.

As indicated in the previous paper, the X-ray method possesses an advantage over the weighing technique in relative permeability experimentation in that the core need not be removed from the holder for the purpose of making a saturation measurement. Furthermore, the actual distribution of fluid and the effects upon that distribution of inflow and outflow heads may be investigated. And errors due to gas bubbles or loss of liquid that are frequently sources of error in volumetric methods of saturation determination are avoided.

PRINCIPLE OF THE METHOD

The energy in an X-ray beam that has passed through an absorbing material is expressed by the well known formula:

$$E = E_o\, e^{-\mu c d} \qquad (1)$$

where E_o is the energy in the incident beam, μ the mass absorption coefficient, c the density or concentration of absorbing material, and d is the length of path of the beam in the absorber. The coefficient μ varies with the wavelength of the radiation as well as with the absorbing material.

The output of an X-ray tube varies in an approximately linear manner with the tube current, but to the second or higher power of the anode voltage. Moreover, the quality or wavelength distribution of the radiation varies with the voltage.

[1] References given at end of the paper.

Manuscript received at the office of the Petroleum Branch October 4, 1949. Paper presented at the Petroleum Branch meeting in San Antonio, October 5-7, 1949.

Current regulators have been developed which satisfactorily control the tube current, but entirely suitable voltage regulators are not readily available. Consequently, in this application, as in the earlier apparatus, a second beam is taken off at a small angle to the main beam and used as a control.

For the greatest precision in the measurement of X-ray absorption at various saturations, homogeneous or monochromatic X-rays should be employed unless a standard can be used that always exactly matches the unknown in absorption qualities. If more than one wavelength is present, the longer waves will be strongly absorbed by the first sections of the absorber making the fraction of the energy removed per unit of path decrease with the thickness traversed. In core studies, however, the use of a homogeneous beam is generally not practical because of the great loss in intensity that is incurred in monochromating the X-rays. Moreover, tests have shown that for moderate concentrations of tracer materials in the core, the error introduced even in assuming a constant value of μ will be small. And further corrections may readily be made by calibrating the system with absorbers consisting of cells of varying thickness filled with the test fluid.

In Fig. 1, I_1 and I_2 represent the currents flowing in the monitor and test ionization chambers, respectively, due to the passage of X-rays through the gas inside the chambers. These currents are directly proportional to the X-ray beam intensity as long as the voltages applied to the ionization chambers are sufficient to render recombination of the ions negligible. Consequently the current flowing in resistance R_1 due to the ionization current in chamber 1 may be written:

$$I_1 = k_1 E_1 = k_1 E_o e^{-\mu_m c_m d_m} = C_1 E_o \qquad (2)$$

where c_m and d_m, the density and thickness of the absorber in the monitor beam, are fixed quantities, and μ_m is essentially constant for the small variations normally encountered in the intensity of the incident beam. The current I_1 is therefore a measure of the X-ray tube output.

For the test core the ionization current may similarly be expressed as:

$$I_2 = k_2 E_2 = k_2 E_o e^{-(\mu_t c_t d_t + \mu_a c_a d_a)} \qquad (3)$$

where the subscript t designates the test core and a refers to the absorbing fluid containing the tracer material. Since μ_a, c_t, and d_t are constant, or nearly so, for a given core section, they may be incorporated in the constant of proportionality. Also the effective density or concentration of the tracer material in the core is given by:

$$c_a = f\rho\gamma \qquad (4)$$

where f and ρ are the porosity and saturation of the core and γ is the true density of the fluid containing the tracer. Therefore:

$$I_2 = C_2 E_o e^{-\mu_a f\rho\gamma d_t} \qquad (5)$$

In the inverse feed-back amplifier, of voltage gain g, indicated in Fig. 1, the entire output voltage, ir_1 is fed back in opposite polarity to the input voltage IR_1 so that:

$$g(IR_1 - ir_1) = ir_1 \qquad (6)$$

or:

$$ir_1 = \frac{g}{g+1} IR_1 \qquad (7)$$

When the gain is high, as in the present application, the output voltage is for practical purposes equal to the input voltage. The output is thus not only independent of the gain, but the swing of the grid voltage is reduced by the factor g and the linearity of the amplifier is consequently improved. Moreover, by the use of feed-back, the effective grid to cathode resistance of the first tube is increased and the time constant of the input circuit is reduced.

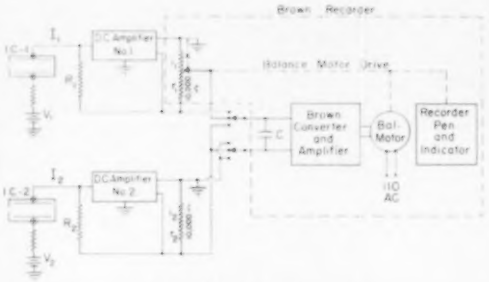


FIG. 1 — SCHEMATIC AND BLOCK DIAGRAM OF THE X-RAY MEASURING AND RECORDING SYSTEM.

Therefore to a good approximation:

$$i_1 r_1 = I_1 R_1 = C_1 E_o R_1 \qquad (8)$$

Similarly:

$$i_2 r_2 = I_2 R_2 = C_2 E_o R_2 e^{-\mu_a f\rho\gamma d_t} \qquad (9)$$

and:

$$\frac{i_2 r_2}{i_1 r_1} = \frac{C_2 R_2}{R_1} e^{-\mu_a f\rho\gamma d_t} = C_3 e^{-\mu_a f\rho\gamma d_t} \qquad (10)$$

since R_1 and R_2 normally remain fixed for a given experiment.

In practice the ionization currents are fed to two identical DC amplifiers which were patterned after the feedback amplifier of A. O. Nier, E. P. Ney, and M. G. Inghram.[2] As the internal gain of these amplifiers is about 500, the input and output voltages are very nearly equal. In the present application r_1 is a 10,000 ohm 10-turn helipot, the slider of which is geared to the balancing motor of a Brown Electronik Recorder. The test core amplifier has a fixed output resistance of 10,000 ohms. As indicated in Fig. 1, the input of the recorder amplifier is connected between the high side of the fixed resistor and the slider of the helipot. The recorder thus serves as a null indicating instrument. In response to a signal the amplifier tends to drive the balancing motor in such a direction that a balance will be restored. The arrangement is such that the helipot will be driven through its 10 turns while the recorder pen is moved across the full scale of the chart. The pen position thus indicates directly the fraction of the output of amplifier No. 1 which is equal to the output of amplifier No. 2. In operation the standard absorber in the monitor beam is first adjusted until the voltage drop across the helipot is equal to or a little greater than the drop across the output of amplifier No. 2, the saturation of the test core having its minimum value. For any saturation of the test core the balancing motor comes to rest indicating zero input when:

$$i_2 r_2 = x i_1 r_1 \qquad (11)$$

where x is the fraction of the total helipot resistance that lies between the movable contact and the grounded point.

Substituting Eq. (10) and letting x_c be the value of x when f or $\rho = 0$,

$$x = x_c e^{-\mu_a f\rho\gamma d_t} \qquad (12)$$

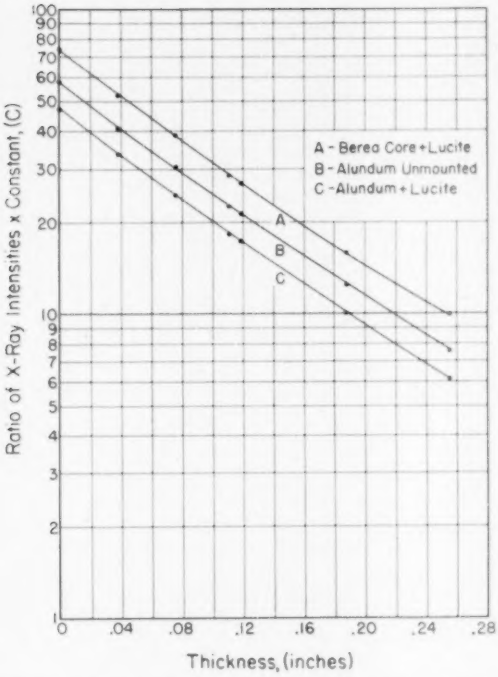


FIG. 2 — THE VARIATION OF INTENSITY OF A TRANSMITTED X-RAY BEAM WITH THICKNESS OF AN ABSORBER CONSISTING OF AN AQUEOUS SODIUM IODIDE SOLUTION (CALIBRATION CURVE). RECORDER READINGS ARE PLOTTED AS ORDINATES.

Again for a given core section and test fluid, μ_s, f, γ, and d, may be treated as constants. Then:

$$x = x_s e^{-\mu' p} \qquad (13)$$

and a plot of the logarithm of the recorder reading against the core saturation should be a straight line, the position of which is readily determined from the recorder readings for both the dry and saturated core. In practice, such semi-log plots are generally slightly concave upward due to the variation of absorption of the tracer fluid with wavelength. However, if the concentration of tracer is low and a monitor absorber is selected which approximately matches the test core in its absorbing qualities, the deviation from linearity will be small.

Equation (12) may also be applied in determining the porosity of a core. Since the absorption of X-rays depends upon the number of absorbing molecules in the beam and not on their specific location, cells containing various thicknesses of the tracer fluid may be inserted in the path of the X-rays, along with the dry core, and the transmission determined. The thickness of tracer liquid that gives the same ratio of x/x_s as is found for the saturated and dry core will be equal to the product of the length of path of the X-ray beam in the core and the porosity of the core.

In Fig. 2 the recorder reading, which is proportional to the ratio of the intensity of the beam that has passed through the test liquid to the incident beam, is plotted as a function of cell thickness for three combinations of alundum and Berea cores in series with the cell. Lucite was used with the Berea sample to keep the deflection on the scale. The three lines are parallel within the error of reading the chart thereby verifying the theory. By using this liquid to saturate a core the porosity may be determined by the method described above. Also the thickness of tracer fluid corresponding to a fully saturated core can be read from the curve and the deviation from linearity on the semi-log saturation plot determined, or a true calibration curve of recorder reading vs. per cent saturation prepared.

In deriving the above equations, the assumption was made that the pore space in the core not occupied by the tracer fluid was filled with gas or a liquid with a very low absorption coefficient. This hypothesis, although convenient, is not necessary. If one liquid is a weak absorber in comparison with the other, it is easy to show that a semi-log plot of the recorder reading against saturation of the tracer containing liquid will be approximately a straight line when the deflections for zero and 100 per cent saturation are taken equal to those for 100 per cent saturation of the weak absorber and the tracer liquid respectively.

DESCRIPTION OF THE APPARATUS

The same X-ray tube and power supply have been used as described in the previous paper. However, a Westinghouse electronic tube current regulator and a Sorenson voltage regulator have been added to help stabilize the X-ray output. The latest arrangement of the apparatus is shown by the photograph of Fig. 3, while a schematic diagram of the X-ray tube and the beam paths is shown by Fig. 4. The test core, C_s, can be driven automatically by the motor so that the entire length of the core can be scanned in either direction with the X-ray beam. Since the beam at the core is approximately $\frac{1}{8}$ in. wide in the direction of scan, the average value of the saturation will be obtained over this length of core. However, the exact position of any abrupt change in saturation may be accurately determined when the core is scanned in both directions.

The ionization chambers have parallel plate electrodes as shown in Fig. 4. The plates in both chambers are one inch wide, and the separation is also one inch, the length being

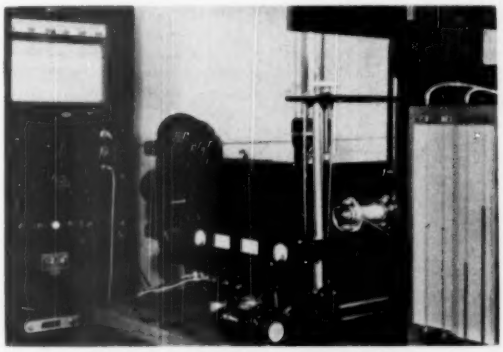


FIG. 3 — VIEW OF APPARATUS.

eight inches in IC-1 and 16 inches in IC-2. The plates, which are of aluminum, are mounted in brass tubes having lucite windows on the ends through which the X-rays enter. The chambers are filled with Freon gas to increase their efficiency and 45 volts is normally applied to the electrodes. Tests at higher voltage have shown no improvement in linearity and only a slight increase in ionization current. Freon gas has been used in spite of its comparatively low efficiency because of its stability, availability and freedom from harmful effects. The electrodes are insulated from the walls of the chamber by means of Teflon.

The first stage of each amplifier, consisting of a 959 acorn tube and grid resistor of 10^9 or 10^{10} ohms, is mounted in a shielded can next to the ionization chamber to reduce the grid capacitance, diminish the leakage paths and minimize possible interference from external sources. The other stages in each amplifier consist of two 1S5 tubes and a 6J5 output tube. The amplifiers are entirely battery operated and all components are completely shielded.

As indicated before, the Brown Recorder is used as a null indicating device which records the fraction of the output of amplifier No. 1 which is required to balance the output of amplifier No. 2. The signal is connected directly to the input of the recorder amplifier, the bridge circuit being disconnected entirely. The chart can be driven at the same speed as the test core or at some multiple speed, if desired, to give an expanded scale for the curve. Scanning speeds of $\frac{1}{2}$ in., $\frac{3}{4}$ in., 1 in. and $1\frac{1}{2}$ in. per minute have been provided.

The switch indicated in Fig. 1 is used for connecting the total output of each DC amplifier directly to the recorder in order to set the zero adjustments to give zero output voltage when there is no input signal. This is indicated when the recorder pen does not move in either direction. The amplifiers should be adjusted to zero output before each core scan or measurement since they are subject to slight drift even after the warm-up period. The zero position is also subject to change from excessive vibration. Extensive measures have been taken to reduce this drift and interference as much as possible, but conditions are not favorable for eliminating them entirely. However, with care in operation the results are quite satisfactory.

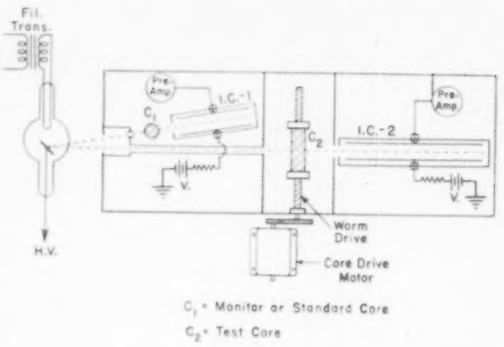


FIG. 4 — SCHEMATIC DIAGRAM OF X-RAY BEAM PATHS.

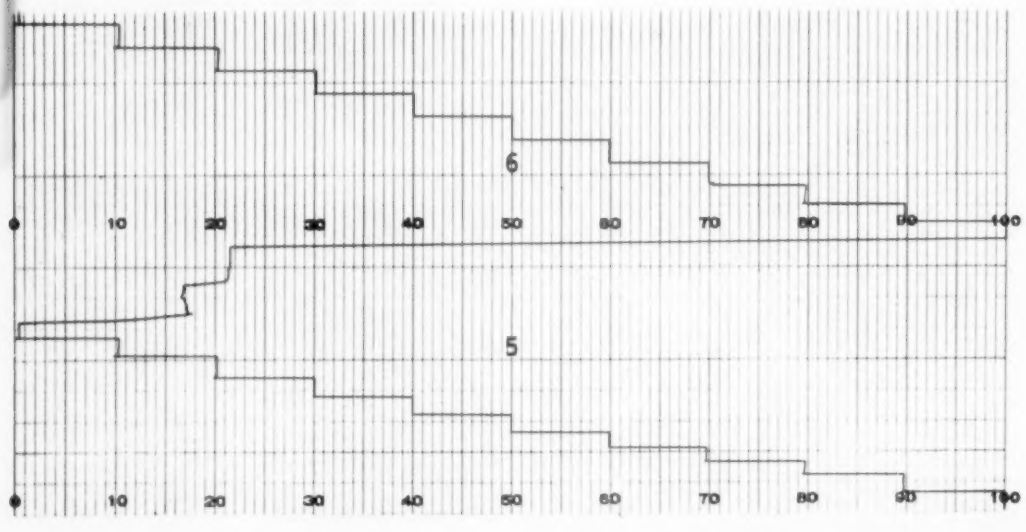


FIG. 5 — RESPONSE OF RATIO METER TO EQUAL INCREMENTS IN VOLTAGE RATIO.

TEST OF RATIO METER

To test the amplifiers and, at the same time, obtain information on the suitability of the apparatus for determining the ratio of currents or voltages, potentials were applied to the preamplifier tube grids by means of potentiometers. The potential divider in the grid circuit of amplifier 2 was so set that the voltage could readily be reduced to zero in ten equal increments and the grid of amplifier number 1 was biased until the recorder registered full scale. Fig. 5 shows the results of the test. As the voltage ratio was decreased from unity to zero by tenths, the recorder pen moved approximately one major division at a time. Deviations from the exact values are due in part to drift of the amplifier zero and in part to lack of linearity in the helipot resistance.

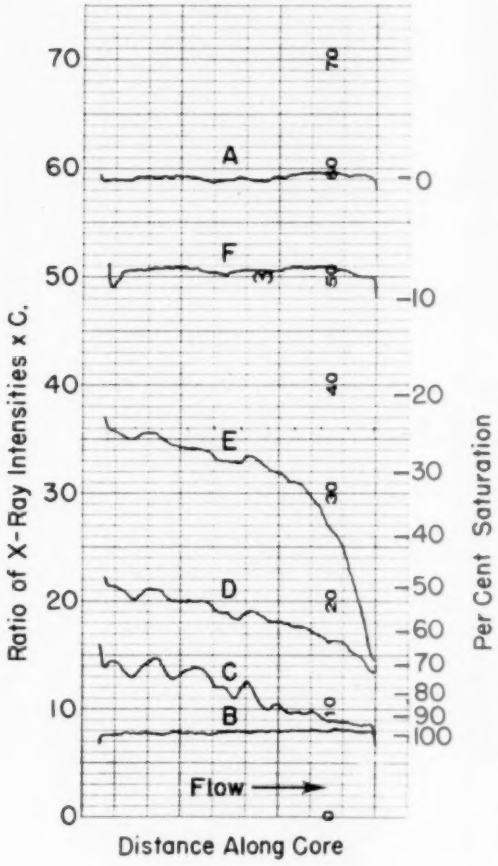


FIG. 6 — WATER DISTRIBUTION IN AN ALUNDUM CORE SUBJECTED TO A GAS DRIVE. TRACER, SODIUM IODIDE. A — DRY CORE, B — SATURATED CORE, C. D. E — SATURATION DISTRIBUTION AT VARIOUS STAGES OF THE DRIVE, F — INTENSITY THROUGH CORE AFTER FLOWING ONE PORE VOLUME OF DISTILLED WATER (THE SATURATION SCALE AT THE RIGHT IS NOT APPLICABLE TO CURVE F DUE TO THE ADDITION OF A THIRD COMPONENT, DISTILLED WATER).

CORE EXPERIMENTS

Saturation Distribution During Gas Drive

As a preliminary step in a series of experiments on multi-core sections, the distribution of fluid in a core subjected to a gas drive was determined at various stages of desaturation. It is well known that water tends to accumulate at the outflow face of such a core, due to capillary forces or the "end effect," and this behavior has been observed experimentally.[1,2] The new apparatus is very convenient for demonstrating such effects and is also well adapted for the investigation of saturation variations inside a core. In this case it was considered desirable to scan an undivided core to obtain a picture of the liquid distribution before proceeding with the experiments which involved cutting the core into sections. As stated before, the width of the beam in the direction of scan was approximately $\frac{1}{8}$ in. Its height was roughly $\frac{1}{4}$ in. These dimensions can undoubtedly be reduced, if necessary, to obtain better resolution.

An alundum core approximately four inches long and one inch in diameter was mounted in lucite, inserted in the X-ray unit core holder, and scanned in its dry state. It was then saturated, after evacuation, with an aqueous solution consisting of 200 grams of sodium iodide per liter. This concentration is high, but since no ill effects have been observed, with the exception of a mild corrosive action when metal fittings are used, there seemed to be no necessity for reducing the tracer concentration. The air permeability of the core at atmospheric pressure was 410 md. and the porosity, as computed from the amount of sodium iodide solution required for saturation, was 23.8 per cent. This compares favorably with the value 24.3 determined by the method of Equation (12). The dry scan, depicted as the trace *A* of Fig. 6, shows that there are no major cavities or unconformities along the central section of the core. The small differences in absorption observed in passing from one end of the sample to the other may easily be accounted for by small variations in the core diameter.

Trace *B* is for the saturated core. A slightly greater absorption at the inflow than at the outflow end indicates either that the core was not entirely saturated at the outflow end or the porosity was somewhat lower there. The maximum difference in saturation — about three per cent — is of little significance in this experiment. Furthermore, since great accuracy in saturation determination was not required in this experiment, a scale of saturation based only on the logarithmic formula has been appended to the chart. Due to the previously mentioned change of absorption with wavelength the indicated saturations will be a little higher than the true values except near the ends of the scale. Curves *C*, *D*, and *E* follow the course of the saturation distribution during progressive desaturation by flow of nitrogen, which had been bubbled through water, starting with an inflow pressure of approximately 3 psi and then increasing the gas pressure by steps until the differential pressure across the core was about 12 psi. No attempt was made to run the experiment at each pressure until equilibrium had been attained. Shortly after the initiation of gas flow, for example in trace *C*, large variations were observed in saturation along the length of the core. Such changes are apparently due to gas pockets, trapped inside the core, which are not readily flushed out by the flow of liquid and gas. In traces *C* to *E* the piling up of water at the outflow face due to capillarity became more and more evident as the gas pressure was increased. Following this phase of the study the tracer material was washed out of the core preparatory to the first step of the multi-core experiment. Curve *F* shows that distilled water is quite effective in flushing the sodium iodide solution

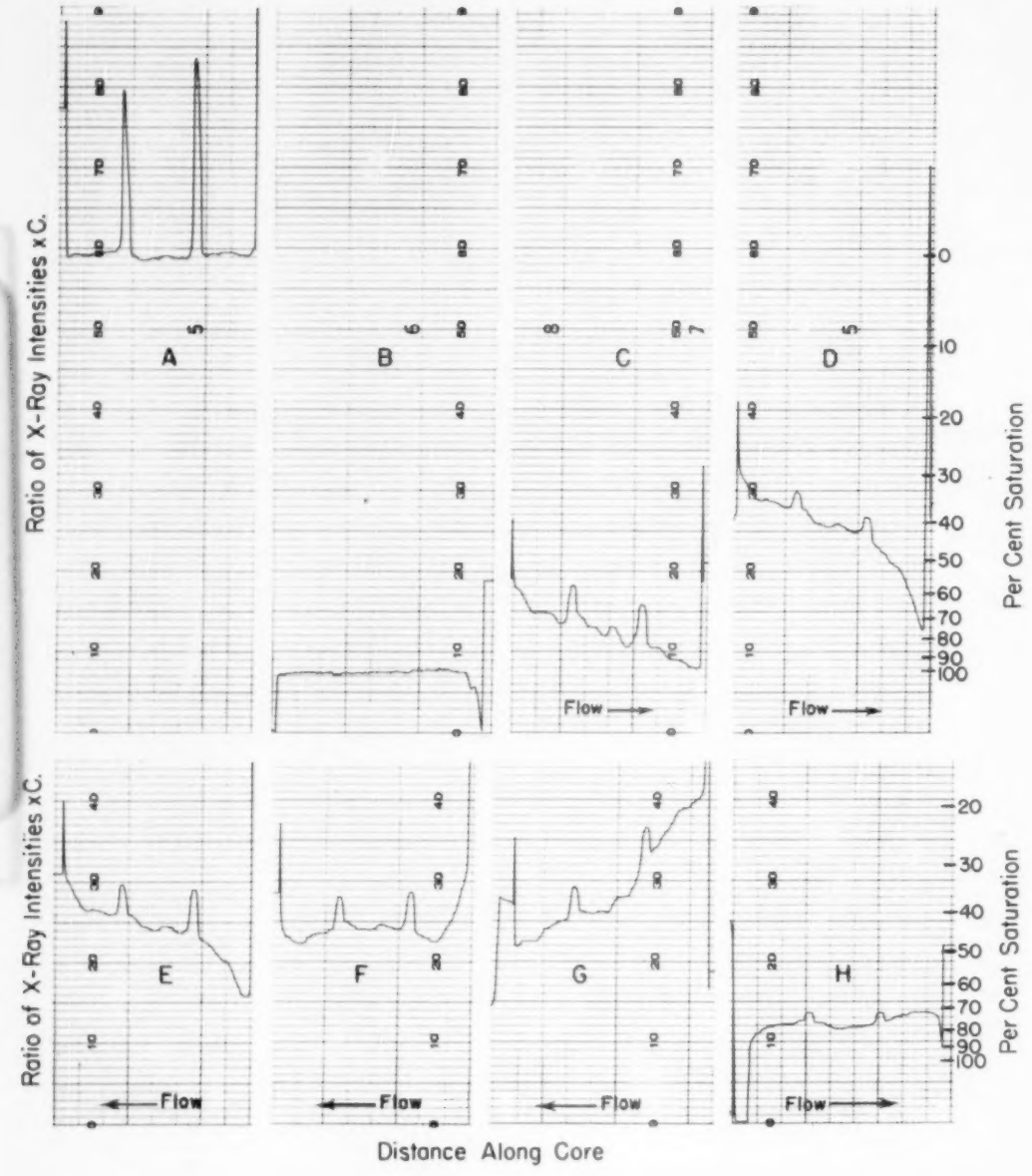


FIG. 7 — THE VARIATION OF TRANSMITTED BEAM ENERGY AND WATER SATURATION IN A THREE SECTION CORE. ALL CONTACTING SURFACES UNDERGROUND 0.0005". A — DRY CORE; B — SATURATED CORE; C, D, E, F, G — VARIOUS STAGES OF A GAS DRIVE; H — AFTER FLOWING SODIUM IODIDE SOLUTION. THE VERTICAL CHART LINES ARE NOT COORDINATED WITH THE CORE LOCATION.

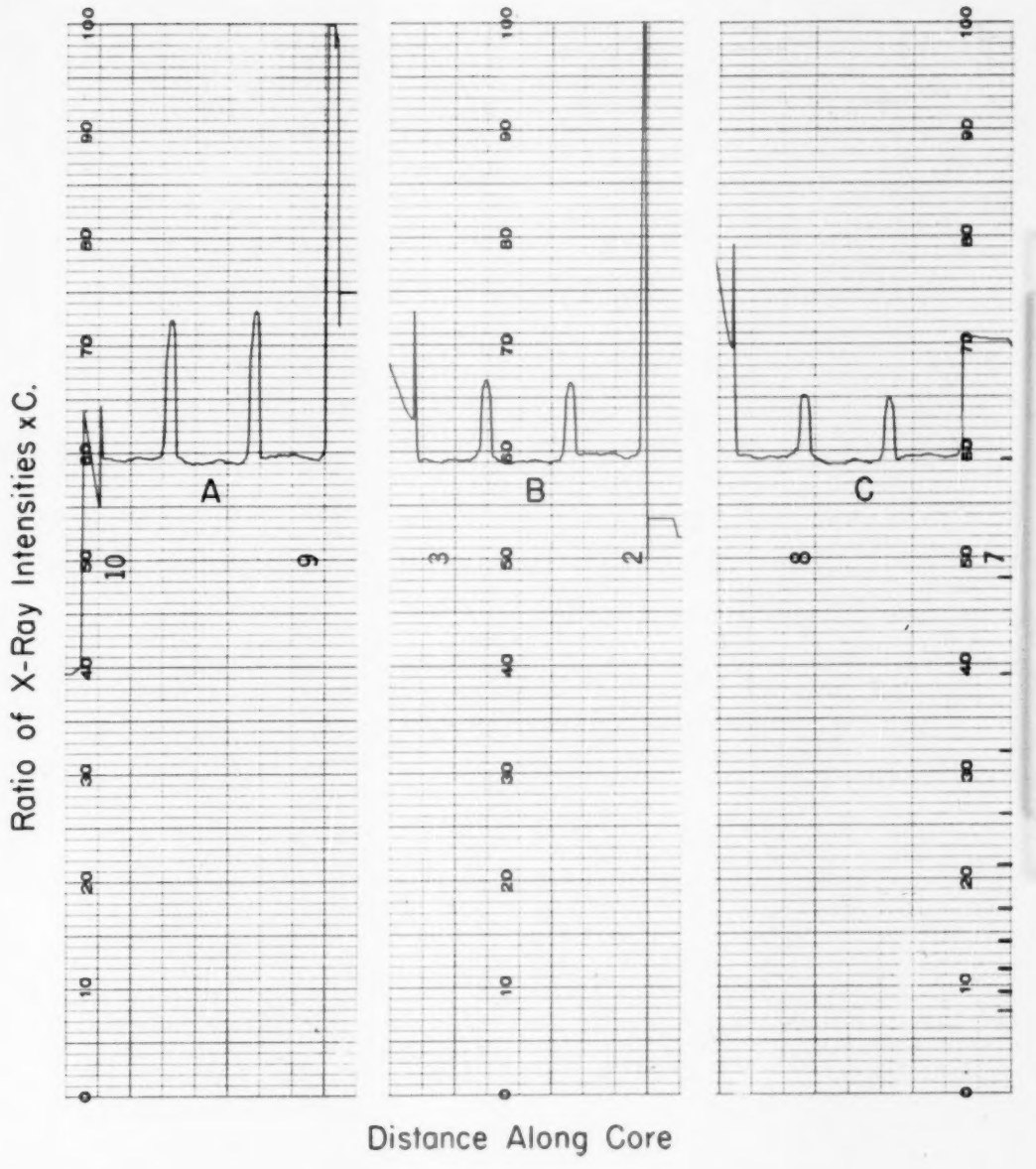


FIG. 8 — THE INTENSITY OF THE TRANSMITTED X-RAY BEAM THROUGH A DRY, THREE SECTION CORE, UNDER VARIOUS COMPRESSIVE FORCES INCREASING FROM A TO B TO C. TEST CORE FLUSH WITH ENCASING LUCITE.

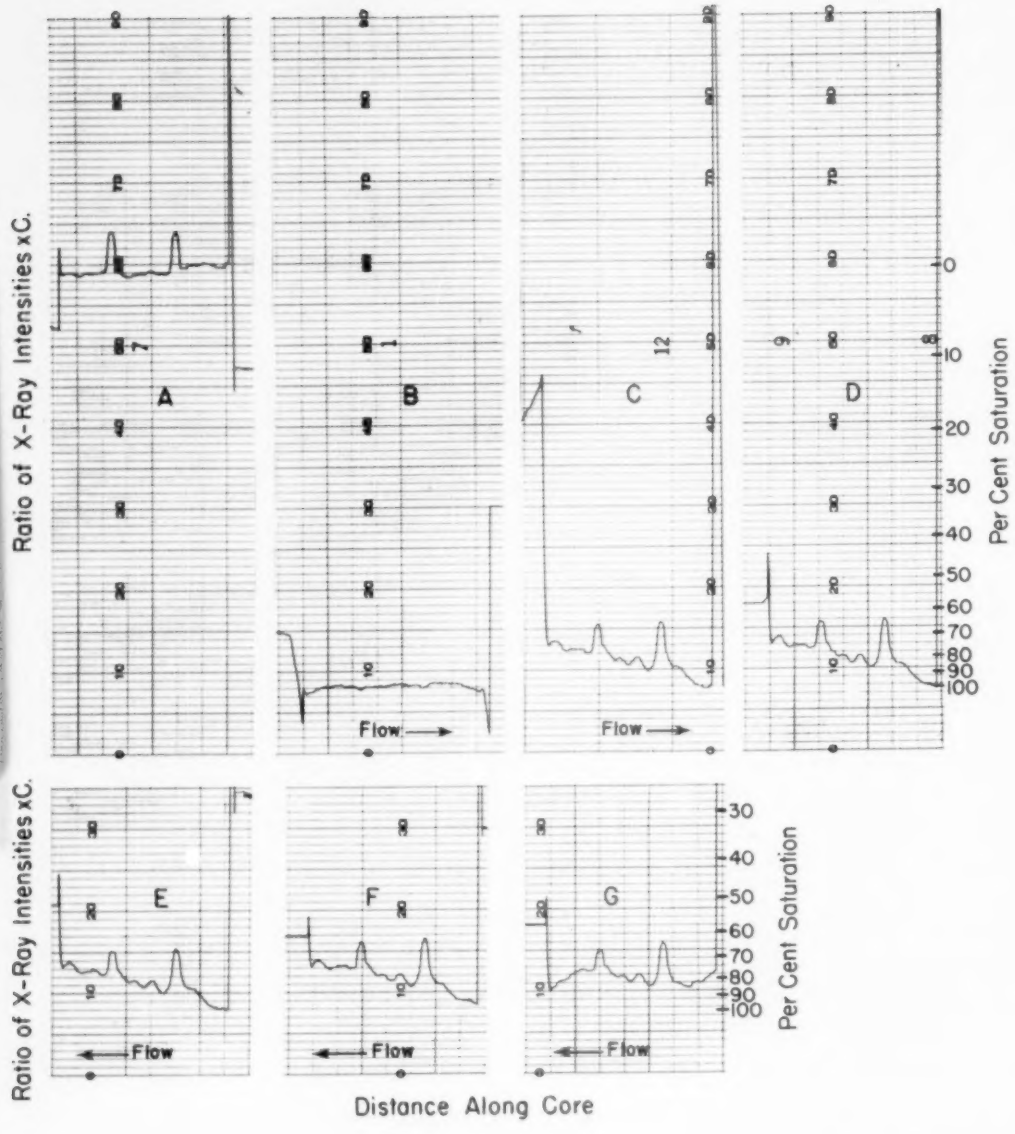


FIG. 9 – THE VARIATION OF TRANSMITTED BEAM INTENSITY AND WATER SATURATION IN A THREE SECTION CORE. ALL CONTACTING SURFACES CUT FLUSH WITH ENCASING LUCITE. A – DRY CORE; B – SATURATED CORE; C, D, E, F, G – VARIOUS STAGES OF SATURATION DURING A GAS DRIVE.

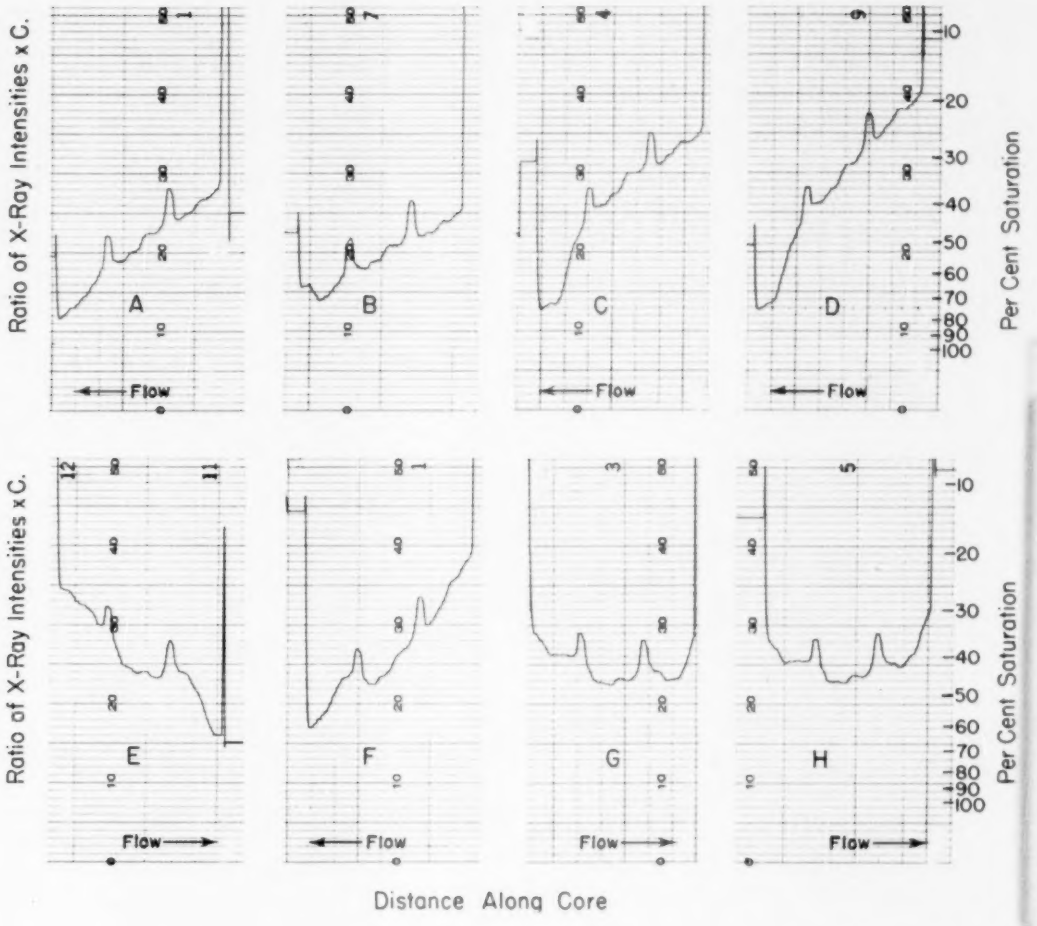


FIG. 10 — THE VARIATION OF TRANSMITTED BEAM INTENSITY AND WATER SATURATION IN A THREE SECTION CORE AT VARIOUS STAGES DURING A GAS DRIVE. (CONTINUATION OF FIG. 9.)

out of the core. Only one pore volume of liquid had been collected at that stage, but the absorption already was reduced nearly to the value expected for a core containing water devoid of iodide tracer.

Effect on Fluid Distribution of Sectioning a Core

A method has recently been described[4] for measuring relative permeabilities of short cores in which core sections are pressed tightly against the test piece on both the inflow and outflow ends. All three sections are mounted in lucite and the cores themselves are undercut slightly at the contact faces in order that leak tight joints may be provided on compression of the lucite. Pressure taps are inserted at the junctions and the assumption is made that end effects will be avoided as the three pieces will for practical purposes behave as a single continuous core. A series of experiments was undertaken with the X-ray apparatus to test the hypothesis that no discontinuities would be found at the junctions of the cores.

After several hundred milliliters of water had been flowed through the core used in the previous experiments, it was cut into three sections corresponding to inflow and outflow heads and a test core. All four contacting faces were then undercut 0.0005 in. below the lucite sleeve. The three sections were next dried and inserted in a core holder in which considerable pressure could be applied parallel to the length of the speci-

men. With the exception of the joints the dry scan, shown as the trace *A* in Fig. 7, is in all respects nearly an exact duplicate of the dry scan of the core in its original condition. The marked increase in intensity at the joints definitely indicates a lack of uniformity in core structure at these points.

Evidently, under the conditions of this experiment, the three sections are not equivalent in all respects to a single core. Trace *B*, of the saturated core, also compares favorably with that for the undivided piece. The junctions may now be located, however, by small dips in the record which indicate that the bulk concentration of the tracer is greater in the cavities between the sections than in the cores themselves. When the third scan, *C*, was taken, after the start of a gas drive, peaks in the saturation curve were present where the dips had previously occurred. Due to the gaps between sections, the calibration curve for the core segments is not applicable at the junctions nor are the saturation scales at the right of the figure valid there. Rather, at the junctions, the X-ray energy reaching the detector will consist of two or more components arriving from parallel beam elements, one of which passes through the gap between the sections while the others traverse portions of the cores. Calibration curves, determined as before but based on the maximum and minimum deflections observed at the junctions, indicate that the dips will just disappear when the saturation in both the cores and gaps is approximately 80 per cent (60 per cent in Fig. 9). A more precise calibration, obtained by considering parallel elements, indicates, however, that both of these figures are too high and that all the peaks at the junctions for the partially saturated

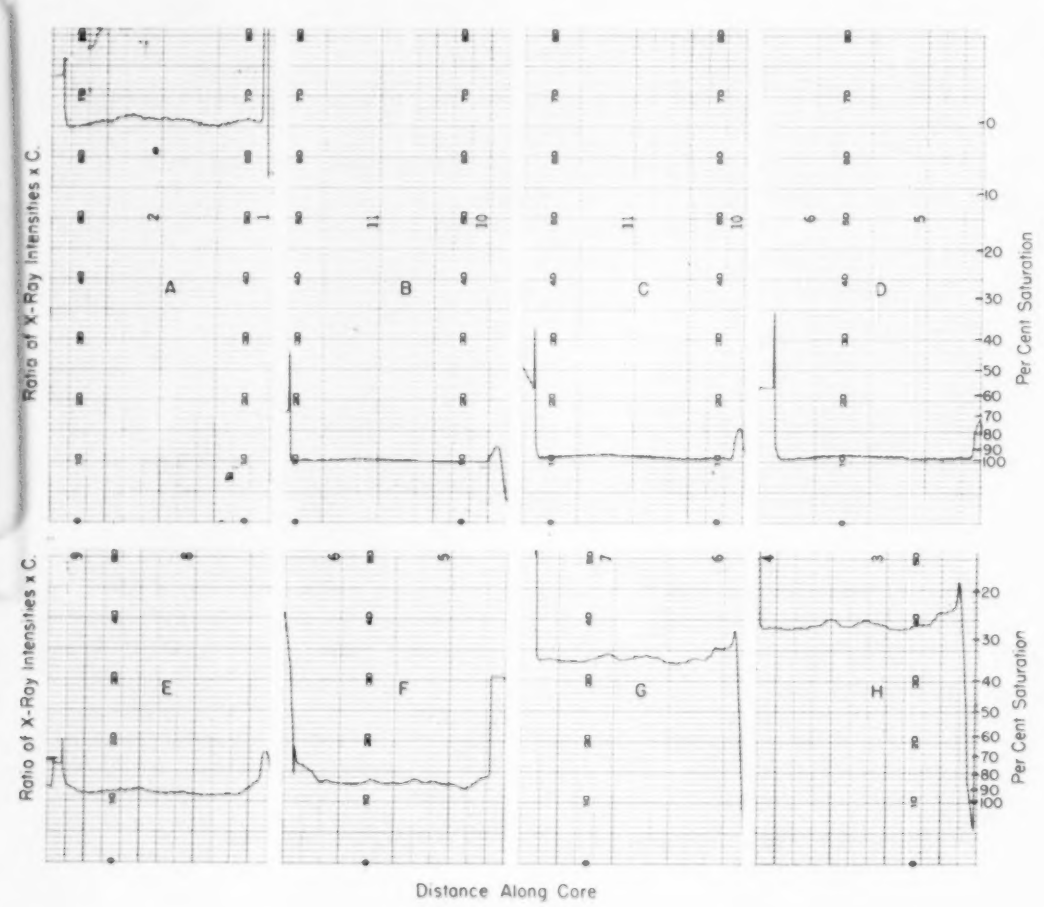


FIG. 11 — THE VARIATION OF TRANSMITTED BEAM INTENSITY AND WATER SATURATION WITH DISTANCE ALONG A CORE DURING DESATURATION BY THE CAPILLARY PRESSURE TECHNIQUE. BARRIER AT RIGHT, CORE UNMOUNTED. DISPLACING MEDIUM, GAS. A — DRY CORE; B — SATURATED CORE; C, D, E, F, G, H — SATURATION DISTRIBUTION AT VARIOUS STAGES AS GAS PRESSURE WAS INCREASED.

states must be ascribed to a local concentration of gas in excess of that in the neighboring segments. Exact determinations of these saturations are difficult, if not impossible, because of the limited response of the detectors and uncertainty in the effective width of the gaps.

Curve *D* shows the effect of continuing the gas flow at increased pressure and trace *E* was taken after gas had flowed slowly through the core in the reverse direction at a rate of about 2.5 milliliters per minute for 40 minutes. Not much redistribution of fluid took place under these conditions. However, when the pressure drop over the core was increased to about 5 psi the liquid distribution changed rapidly. Curve *F* shows the distribution after gas had been flowing at 1 ml/sec for three hours, while *G* corresponds to 2 ml/sec for the next hour. Once gas has collected at the junctions it is not readily displaced by flowing sodium iodide solution as indicated by curve H, which was made after a large quantity of sodium iodide solution had flowed through the core at 9 psi.

As the next step the ends of the test core were finished flush with the lucite after washing with water, and the dry core was examined as before. Fig. 8 shows the results of three scans with compressive forces applied to the core assembly increasing from left to right. Since it was evident that sufficient force could not be applied to close the gaps, the remaining contacting surfaces were immediately ground flush with the lucite preparatory to the final phase of the experiment.

The core sections were next inserted in the core holder and a compressive force applied that seemed on the verge of cracking the lucite. The top left trace of Fig. 9, corresponding to the dry core, still shows the discontinuity although it is not so pronounced as before. Curve *B* is for the liquid filled core. The drift of the amplifiers in this case was more than usual and the latter trace appears to be a little too high. After the flow of several pore volumes of sodium iodide solution failed to increase the saturation, the flow of nitrogen was started at a pressure slightly above the displacement pressure and trace *C* was obtained shortly thereafter. As before, the absorption of X-rays is least at the junctions of the core sections indicating the existence of a saturation discontinuity and the collection of more gas at the interface than corresponds to the gas-water ratio in other parts of the core. On the basis of these experiments it therefore appears that even by grinding the core faces flush with the encasing lucite the contact cannot be made sufficiently intimate to eliminate entirely all boundary effects. The remaining scans of Fig. 9, as well as those of Fig. 10, illustrate the saturation distribution which accompanies the flow of gas through the core at various pressure gradients. The trapping of excessive gas at the junction is evident in all of the examples. After taking curve *C*, the core was shut in for 24 hours with no appreciable change of fluid distribution, as indicated by trace *D*. Neither did the flow of gas for one hour in the reverse direction at a very slow rate, under a head of one cm. of Hg., nor a flow for one and a half hours at four times that gradient change the picture appreciably as shown by traces *E* and *F*. However, at 11.3 cm Hg. pressure the distribution, *G*, was altered considerably in one hour.

To obtain *A* of Fig. 10 the gas pressure was increased to 17.9 cm. of Hg. for 40 minutes and additional liquid was recovered. This time, *B*, the distribution changed when the core was shut in with pressure applied for 16 hours. Further liquid was produced and curve *C* obtained after flowing for 30 minutes at 22.9 cm. of Hg. pressure. In *D* gas had flowed for three hours at a pressure of 22.0 cm. of mercury, while in *E* the flow was reversed for 30 minutes at 22.5 cm. Hg. It was again reversed in *F* for 15 minutes at approximately the same pressure. On stopping the flow after it had continued for five minutes from left to right, *G* was obtained. The saturation distribution then remained practically unchanged for 30 minutes while flow was continued in the same direction, as shown by trace *H*, at 1.6 cm. Hg. pressure.

If the results obtained after sectioning the core can be considered to be representative of such samples, it appears that a discontinuity in capillary properties must be expected over at least a portion of the core face in passing from the body of a core into the space between the sections. How serious this effect will be in the measurement of relative permeabilities has not yet been determined. In many of the experiments there seems to be no noticeable piling up of liquid at the outflow end of the test core. However, if the observed saturation gradients persist when flowing mixtures, unequal pressure drops in the two phases will normally be encountered. Moreover, at the joints equilibrium will generally be attained only after long intervals of flowing and considerable variation with time will probably be observed.

In addition to the features already emphasized are the sharp saturation breaks that occur at the same location in the core in all the experiments. Particularly outstanding in this respect are the traces *C* of Figs. 6, 7 and 9. These variations were entirely unexpected as this core was found, on first scanning, to be more uniform than the average.

Fluid Distribution During Desaturation by Capillary Pressure Method

In experimentation of the capillary pressure type in which semipermeable barriers are employed, it is generally tacitly assumed that, at equilibrium, a discontinuity in saturation will exist at the interface between the core and the barrier. While it appears that this conclusion is justified from a theoretical point of view, no direct experimental tests of its validity seem to have been made. Furthermore, the saturation distribution during the transient stage before equilibrium is established has not been investigated. As the X-ray method of saturation is particularly suited to this type of study, experiments were started with the view of following the liquid distribution in a core during the desaturation process.

For this purpose an alundum core, 9.6 cm. in length and 2.58 cm. in diameter, having a permeability of 220 md. and porosity of 24 per cent was selected. The core was enclosed in a loose fitting lucite sleeve and mounted in a horizontal position so that it could be moved parallel to its length by means of the scanning motor. A spring pressed the core tightly against the barrier and Kleenex was used between the core and barrier to insure phase continuity. Sodium iodide was the saturating liquid and air the displacement medium. The results of the experiments are shown by the recorder charts reproduced in Fig. 11. The traces are of somewhat greater length than in the previous examples due to an increase in chart speed.

The first trace *A* shows the dry scan of the core. While this sample lacks the uniformity of the core used in the previous experiment, it nevertheless was the best of several that were available at the time. Scan *B* is for the saturated core. Here as in all the records in the figure, the barrier is located at the end of the core corresponding to the right end on the scan. Trace *C* was taken two days later after the displacing pressure had been gradually increased to 12 cm. of mercury and about 0.4 ml. of liquid had been collected. The shift of this trace from the original saturated scan is too small to be entirely reliable. Scan *D* was made about an hour after the pressure was increased from 12 to 14 cm. Trace *E* followed by about half an hour a further increase of pressure to 16.6 cm. of Hg., and *F* corresponds to the same conditions one day

later. A scan taken just before the increase of pressure did not differ significantly from *E*. Traces *E* and *F* both indicate a lower saturation at the ends of the core than at the middle. The saturation was again recorded, G, after the pressure had been increased to 30.5 cm. of Hg. and maintained for 20 hours. The pressure was then increased to 39.8 cm. and four days later the core was scanned giving the trace *H*. In contrast to traces *E* and *F*, *G* and *H* show a low value of saturation only at the barrier end. The saturation, corresponding to trace *H*, was approximately 26.5 per cent when computed from the volume of liquid displaced, while the average value from the X-ray surve using the simple absorption formula is about 27.0 per cent.

The shutter was not opened in time to catch the barrier in scan *F*, while traces *G* and *H* show a sharp hump at the core-barrier contact which is followed by the anticipated rapid decrease in intensity due to the high saturation in the barrier itself. A decrease in saturation is apparent at or in the immediate vicinity of the barrier-core contact possibly indicating lack of complete areal contact between the core face and barrier.

DISCUSSION AND CONCLUSIONS

The adoption of a second ionization chamber, which led to the development of the ratio circuit, followed the observation that saturation determinations were variable from day to day and even from one time to another during the same day due to changes in the intensity of the X-ray beam. It is obvious that the apparatus would be considerably simplified if the X-ray source could be stabilized to the extent that sufficient accuracy would be obtained with a single ionization chamber. Moreover, if only approximate saturation values are required, or if minor variations in fluid distribution are not significant, it is quite possible that a recorder comparable to those recently developed or under development by several instrument manufacturers may be sufficiently sensitive and stable to measure the extremely small values of current that are available by this method.

Since an X-ray generator is a rather costly piece of equipment and the output is subject to fluctuations due to variations in the power supply, some preliminary experiments have been made using γ-ray sources. With the materials that have been commonly available, however, the sensitivity has not been as good as with the X-ray apparatus. On the other hand, for studies of saturation in thin core sections a beta ray recording gauge that is commercially available may be satisfactory.

As stated before, the experiments on the three section core indicate that sufficiently intimate contact between the faces to eliminate all boundary effects cannot be obtained. How serious this effect will be on the determination of relative permeabilities is difficult to ascertain and will require more experimentation and analysis. From some aspects the assembly seems to be approximately equivalent to three separate cores. At high pressure gradients the saturation along the length of the test core is far from uniform, as is to be expected, and the pressure gradients will generally not be equal in the two phases. Furthermore, the segregation of gas at the boundaries may be expected to lead to discontinuities in the pressures which may seriously affect the results.

The experiments do show that under certain conditions flow, in the non-wetting phase at least, may be maintained without seriously influencing the saturation distribution in a core. In relative permeability experimentation it therefore appears that the X-ray method may prove to be useful, not only for determining the saturation of a core, but also to indicate when conditions are appropriate for the measurement.

The above saturation distribution measurements on three section cores duplicate essentially some results obtained previously for air-water and oil-water mixtures with the point by point X-ray saturation technique. The measured permeability saturation curves were not reproducible, however, and the results were not considered to be reliable. Whether the inconsistency in results was due to failure to continue flow until equilibrium was attained, to an inherent variability in phase distribution and pressure gradients or to faulty experimental technique is problematical. In any case, work is being continued on this method as it seems to be better adapted than the capillary desaturation technique to the solution of some problems.

ACKNOWLEDGMENTS

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PORE SIZE DISTRIBUTION OF PETROLEUM RESERVOIR ROCKS

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ABSTRACT

An investigation of equivalent pore entry radii in typical samples of petroleum reservoir rock and the pore volume associated with each value of pore entry radius has been made. Theoretical discussions together with experimental procedures for obtaining pore entry radii and the distribution of pore volume with pore entry radii are presented. Experimental results on a number of core samples, along with typical distribution curves, are shown. Data on the per cent of the pore volume filled by mercury at a pressure of 1500 psi are included. The results of re-runs of samples, made possible by regenerative apparatus, show the repeatability of the data and indicate the amount of physical change in the samples by mercury penetration. Theoretical equations for calculating permeability from pore size distribution data were derived and the results of such calculations are compared with measured gas permeability data. The effect of the shape, surface area, and weight of the sample on the pore size distribution of reservoir rocks was investigated experimentally. Mercury capillary pressure curves are compared with those obtained by the porous diaphragm method using gas to displace water.

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[1] References are given at end of paper.

INTRODUCTION

Standard core analysis techniques, in general, lead to quantities which are statistical averages of the varying properties of the samples under examination. Although such statistical information has real value in predicting the gross performance of porous bodies, it fails to provide fundamental information concerning the properties of the porous medium itself or any processes which may be occurring in it. For example, a gas permeability measurement on a core sample is an indirect way of determining an average pore radius for that particular sample. Since there are many combinations of pore radii that will give the same radius, and, hence, the same permeability, no information is obtained on the pore size distribution. Furthermore, similar values in permeability do not imply similarity in other properties of a porous medium. For instance, it is possible to have two core samples with identical permeability which would have different residual oil contents at the end of an air-oil drive, or even different amounts of interstitial water.

It has been recognized for some time by the petroleum industry that a determination of pore size distribution for porous reservoir rocks offered promise of increased understanding of fundamental flow processes in the porous matrix, and therefore of petroleum reservoir performance in general. There have recently been published several methods for determination of pore size distribution in porous materials. A report is given here of the modifications in equipment and technique required to adapt one of these methods to measurements on petroleum reservoir core samples. Although only a few correlations or applications of the method are available for presentation at this time, the technique is brought to the attention of the industry so that the opinions and experience of others with this or similar techniques may be exchanged. It seems possible that the method will have wide application in the future.

METHOD

There are three general methods which may be employed to measure the pore size distribution in naturally occurring rock formations. One method[1] is based on experimentally determined adsorption isotherms for calculating the surface area of the porous medium. Knowing the surface area and the pore volume, a rough estimate of the pore radius can be made. Since this method depends on the thickness and uniformity of the adsorbed layer, the validity of the results would be highly questionable.

A second method utilizes capillary pressure data obtained by static dis-

placement of a wetting fluid from a sample in contact with a semi-permeable porous diaphragm. Although partially successful for the determination of interstitial water curves, the inherent errors and limited pressure that may be used eliminate this method for pore size distribution studies.

A third method, employed by Purcell[1] in an investigation of capillary pressures in reservoir rocks, and by Drake and Ritter[2] in the measurement of the pore size distribution of catalysts, uses a "non-wetting" fluid, mercury. The technique of Drake and Ritter, with modifications, has been applied to the study of pore entry radii and the distribution of pore volume with pore entry radii in reservoir rocks.

In the theory of Drake and Ritter[2] two equations were developed, for the penetration of a "non-wetting" liquid into a porous solid, namely,

$$pR_i = -2\sigma\cos\theta \quad . \quad . \quad . \quad (1)$$

and

$$D(R_i) = \frac{p}{R_i}\,\frac{d(V_\infty - V)}{dp} \quad . \quad . \quad (2)$$

A pressure-volume curve is plotted from experimental data. By graphical differentiation of this curve, values of the derivative in Equation (2) required to evaluate $D(R_i)$ are readily obtained. For a number of values of p, the pressuring curve is differentiated to obtain $d(V_\infty - V)/dp$, R_i is calculated from Equation (1), and $D(R_i)$ from Equation (2). Plotting $D(R_i)$ against R_i gives the distribution curve.

The value of $D(R_i)$ may be determined directly from the pressure volume curve, where $\overline{D(R_i)}$ is the average value of the distribution function in the radii interval R_i to $R_i + \Delta R$. By definition[2]

$$\overline{D(R_i)} = \frac{v_i}{\Delta R} \quad . \quad . \quad . \quad (13)$$

The incremental volume, v_i (fractional), is read off the pressure-volume curve, divided by ΔR, and plotted against $R_i + \frac{1}{2}\Delta R$, giving the distribution curve. This type of graphical differentiation employs the chord instead of the tangent, with accuracy inversely proportional to the length of the increment.

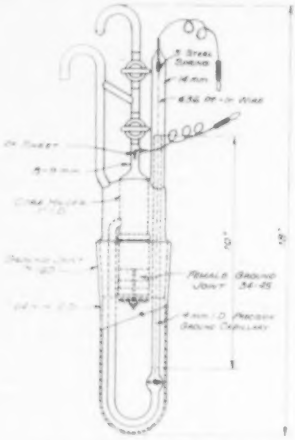

FIG. 1 — DILATOMETER, MOD. IV FOR PORE SIZE DISTRIBUTION MEASUREMENTS.

APPARATUS AND PROCEDURE

An apparatus suitable for determining the pore size distribution in porous media has the following essential components: (1) a system wherein the pressure can be varied from small absolute values (high vacuum) to 2000 psig or higher; (2) a closed system for evacuating the sample and immersing it in the "non-wetting" liquid at a few microns (Hg) pressure; (3) and, finally, a system for measuring the quantity of "non-wetting" liquid that penetrates

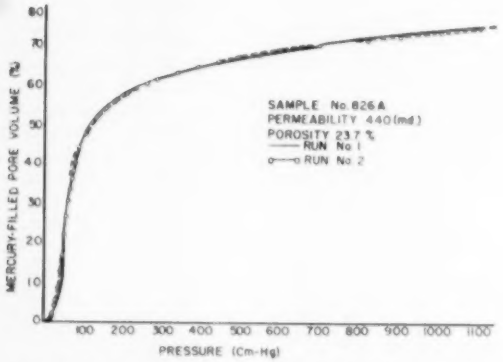

FIG. 2 — MERCURY IMBIBITION CURVES, MERCURY FILLED PORE VOLUME VS. PRESSURE.

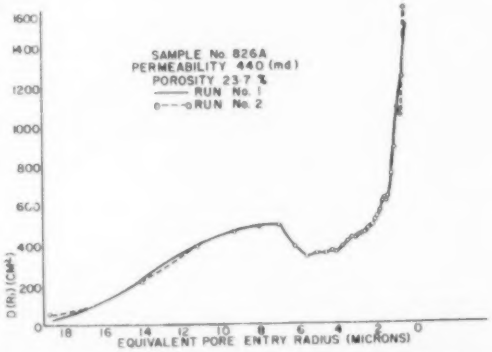

FIG. 3 — EQUIVALENT PORE ENTRY RADIUS VS. DISTRIBUTION FUNCTION.

the sample for a given pressure change. The component parts of the apparatus used in this investigation are described below.

The vacuum system consists of a single stage, high speed, mercury diffusion pump backed by a Welch Duo-Seal, Hy-vac pump. A McLeod gauge and mercury manometer are inserted for pressure (or vacuum) measurements and a tube filled with calcium sulphate ($CaSO_4$) for admitting dry air to the system is included.

The electrical system is used for measuring the quantity of "non-wetting" liquid (mercury) that penetrates the sample for a given pressure change. The essential components are: a type K, L&N potentiometer, a standard 100-ohm resistance, a Rubicon galvanometer, variable resistance boxes, and the platinum resistance wire installed in the capillary of the dilatometer. If the current in the circuit is adjusted to a constant value by means of the potential drop across the standard 100-ohm resistance, the resistance to be measured (the platinum wire) is then determined directly by its potential drop.

Table 1
Dilatometer Calibration

Ohms/cc	Pressure (psi)	Volume Variation (cc)
2.2953	0-1500	± .0006

For readings above atmospheric pressure, a high pressure steel chamber or bomb of sufficient size to contain the dilatometer was constructed. The bomb was connected to a high pressure (2000 psi) nitrogen bottle with suitable pressure gauges, valves, and fittings, and wired electrically for resistance measurements.

The dilatometer used in these studies, Fig. 1, was made of pyrex glass. It consisted of a sample chamber connected to a capillary tube and surrounded by a jacket. This arrangement reduced the pressure differential between the inside

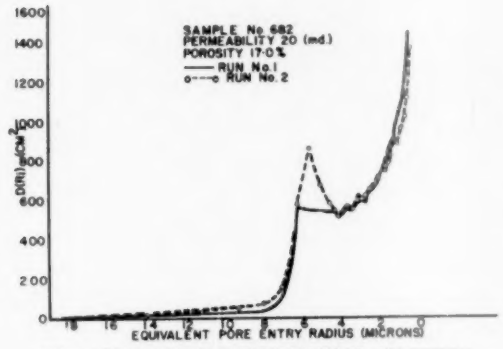

FIG. 4 — EQUIVALENT PORE ENTRY RADIUS VS. DISTRIBUTION FUNCTION.

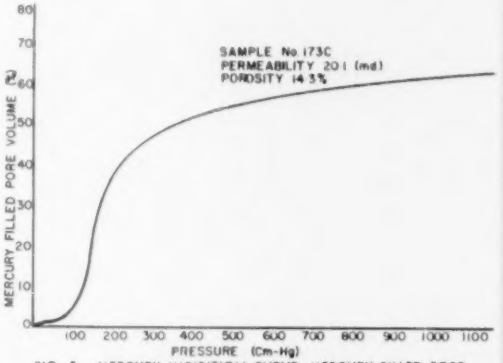

FIG. 5 — MERCURY IMBIBITION CURVE; MERCURY FILLED PORE VOLUME VS. PRESSURE.

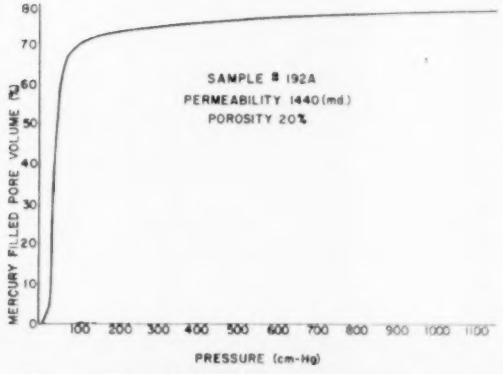

FIG. 6 — MERCURY IMBIBITION CURVE; MERCURY FILLED PORE VOLUME VS. PRESSURE.

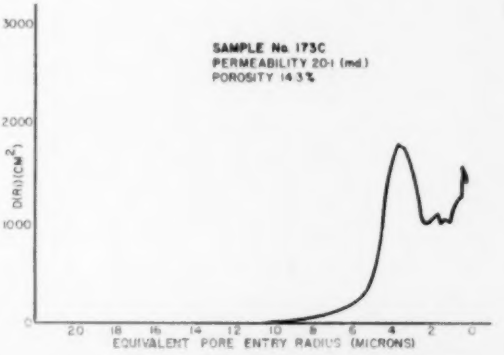

FIG. 7 — EQUIVALENT PORE ENTRY RADIUS VS. DISTRIBUTION FUNCTION.

and outside of the sample chamber to a minimum for all pressures. A No. 36 B&S gauge platinum-iridium wire with appropriate leads for electrical connections to the outside was mounted inside the capillary tube. The dilatometer calibration results are shown in Table I.

After preparations* the sample is placed in the dilatometer and the system is evacuated to a final pressure of 2 to 3 microns of mercury. The capillary tube and the sample chamber are now filled with mercury and the resistance of the capillary wire recorded. The pump is isolated from the dilatometer and dry air is admitted in increments to the system, thereby increasing the pressure on the mercury surrounding the sample. The volume of mercury entering the sample for a given pressure change and, hence, the pore volume associated with this particular increment in the value of pore entry radius, is determined by the increase in resistance of the capillary wire, as the mercury recedes in the capillary upon entering the porous sample. Due to temperature changes in the system by admission of air, or due to an apparent lag in the mercury penetrating the sample for a given pressure increase, or both, the initial resistance readings are too low. It is therefore necessary to wait until the system stabilizes for each pressure increase before the final resistance is measured and recorded. (The ambient temperature changes of the air-conditioned room are considered to be negligible.) This procedure of alternately increasing the pressure and measuring the change in resistance is continued until atmospheric pressure is reached. The inside of the dilatometer surrounding the pressure chamber and the pressure bomb are partially filled with water to minimize temperature variations and to reduce the air space. The dilatometer is then transferred to the bomb and the readings are continued, as above, to 1500 psig or higher, using nitrogen for the pressurizing gas. After converting the resistance readings to volumes of mercury by a previously determined calibration curve, a pressure-volume curve may be plotted for the particular sample.

* Samples are extracted in a Soxhlet extractor using benzene for 24 to 48 hours and dried for at least 24 hours in an oven at 90°C.

Physical Effects of Sample Regeneration

After several experimental tests were made to determine the pore size distribution in reservoir rock samples, it became apparent that much additional information could be obtained if reruns on the test samples were possible. Such information would show, (1) the physical changes in the sample due to the penetration of the mercury into the pore spaces, and, (2), the magnitude and effect of the experimental errors on the repeatability of the data. Also, incompleted runs that were halted during the experiment for various reasons could be started anew. The preparation of a sample for the re-run necessitated the removal of mercury imbibed during the previous run. This was accomplished by vacuum distillation.

The apparatus for sample regeneration consisted of a pyrex glass tube sample chamber surrounded by a heating coil and connected to a Hy-Vac pump through a CO_2 trap.

Samples containing mercury are placed in the sample chamber, evacuated and heated to 180°C. (356°F.) for several hours. When the weight of the sample has been reduced to the weight before imbibition of mercury, it is assumed that all of the mercury has been removed from the sample.

Table II

Measured (Gas) Permeabiilty Before and After Pore Size Experiments

Sample Number	Permeability (md)	
	Before Pore Size Run	After Pore Size Run
261A	0 47	0 50
12A	97 8	94 0
12B	100 8	95 2
174C	37 9	38 2

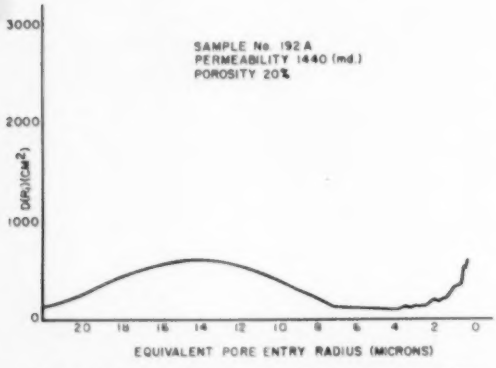

FIG. 8 — EQUIVALENT PORE ENTRY RADIUS VS. DISTRIBUTION FUNCTION.

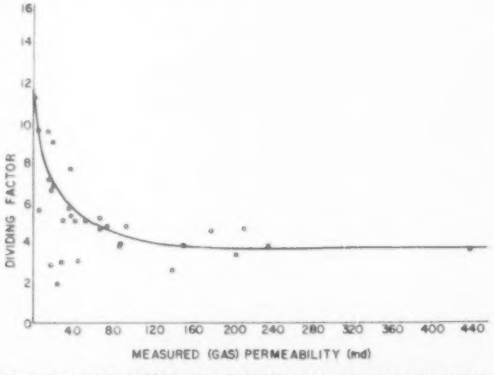

FIG. 9—DIVIDING FACTOR VS. MEASURED (GAS) PERMEABILITY CURVE.

The pressure-volume curves (Fig. 2) for the first and second runs on a reservoir rock sample show excellent repeatability of data and indicate low order of magnitude of experimental errors. Also, the distribution function curves (Fig. 3) for the same sample are very similar. An extreme case, that was observed on only one sample (Fig. 4) gave a broad peaked distribution curve for the first run and a considerably sharper peak for the second run. When the imbibed mercury was being removed from this sample by vacuum distillation a fine gray powder formed on the walls of the chamber and the outside of the sample. The chemical composition of the powder or the cementing material of the sample was not determined.

If the entrance openings to the pore spaces are enlarged by the penetration of the mercury, the gas permeability should be increased by successive pore size distribution runs. To test this, gas permeability measurements were made on a number of reservoir samples before the pore size data were taken and after the removal of the imbibed mercury. No appreciable increase in permeability, Table II, was observed for any of the samples.

It may be concluded from the above tests that the apparatus and procedure for acquiring pore size distribution data on a reservoir sample are satisfactory and that the physical characteristics of the sample are not, in general, altered in the process.

Table III

Per Cent Pore Volume Filled During Mercury Imbibition to 1500 PSIA

Sample No.	Meas. (Gas) Permeability (md)	Pore Volume Filled (%) at 1500 psia	Sample No.	Meas. (Gas) Permeability (md)	Pore Volume Filled (%) at 1500 psia
171C	17	76	190A	93	80
164C	86	69	174B	36	71
171B	2.6	85	173C	20	78
261A	0.5	56	311B	52	68
174C	38	75	192A	1440	82
164B	41	78	169B	30	55
311A	67	58	171D	22	85
161B	7	72	295A	20	84
173D	16	77	261B	<0.01	60
163A	29	78	686	46	57
681	81	61	867	88	77
866	88	73	683	16	62
680	38	61	696	75	61
682	20	50	14564	112	80
826A	140	85	13302	5	68

Table IV

Dividing Factor - Permeability Data

FRL Sample No.	Per Cent Porosity	Meas. (Gas) Permeability (md)	Calculated* Permeability (md)	Dividing Factor
295A	13	19.6	131	6.7
13302	25	5.1	49.7	9.7
14564	20	112	709	6.3
13232	20	140	359	2.6
826A	24	440	1610	3.7
866	21	88.2	357	4.1
867	21	88.4	356	4.0
682	17	20	181	9.1
696	17	75	366	4.9
680	19	38	292	7.7
683	15	16	154	9.6
681	17	67	318	4.7
686	16	46	401	8.7
161B	18	6.7	38.3	5.7
163A	16	29	151	5.2
164B	15	40.8	213	5.2
164C	18	86.1	333	3.9
169B	17	29.6	90.4	3.1
171B	10	2.6	29.4	11.3
171C	12	17.1	50.9	3.0
171D	10	22.1	43.2	2.0
174B	17	35.5	205	5.8
174C	17	37.5	203	5.4
173D	14	16	115	7.2
173C	14	20.1	139	6.9
190A	19	93.0	456	4.9
192A	20	1440	4390	3.1
311A	23	66.6	354	5.3
311B	18	51.9	269	5.2
261A	17	4.5	4.1	0.2
12618	17	237	937	4.0
13996B	20	493	1890	3.8
15809	20	150	566	3.9
6	20	213	1020	4.8
951	23	179	841	4.7
33	20	205	719	3.5
Shale Sample	Not Measurable	0	Negligible	—

*No dividing factor used.

RESULTS

Pore size distribution data have been obtained on 100 samples taken from several reservoir formations. Typical pressure-volume curves are shown (Figs. 5 and 6) for samples that have widely different gas permeabilities. Also, the distribution function curves for the same samples (Figs. 7 and 8) illustrate the type of distribution and the size of the pore entry radii to be expected in the respective permeability ranges.

Pore Volume Filled by Mercury

The per cent of the pore volume filled by mercury at maximum pressure (1500 psig), Table III, varied with the permeability of the sample and ranged from 53 to 85.

According to Equation (1), the smallest pore filled at 1500 psig has an equivalent entry radius of 716Å (1Å = 10^{-8} cm). Hence, a large percentage of the pore space (over 45 per cent for one case above) has entry radii less than 716Å and is not filled with mercury at the maximum pressure used.

An apparatus has been assembled that will increase the pressure range to 10,000 psi. If Equation (1) is applicable[4,5], this will extend the lower radii region filled by mercury to 108Å and will include an estimated 95 per cent of the total pore volume of most reservoir samples.

Geological Correlation

A study of pore size distribution data obtained to date shows that distribution curves for samples from a particular geological formation sometimes have similar characteristics, whereas distribution curves from another formation may have very little in common. If geological formations are found to have characteristic distribution curves in general, the exceptions to this trend may perhaps be ascribed to relatively large amounts of clays and various chemical compounds occluded in the formation. When sufficient data are available, definite conclusions may be made in regard to this possible type of correlation.

Permeability Calculations and Results

Two equations were developed for calculating the permeability of a porous medium from pore entry size distribution data. (See Appendix for derivations). One equation contains the distribution function, and the other, the pressure-volume relationship. The equations are:

$$k = \frac{100\ \phi}{8C} \cdot \frac{\sum_{i=o}^{n} \frac{\overline{D(R_i)}\ \overline{R_i^4}}{x_i^2\ \overline{R_i^2}}}{\sum_{i=o}^{n} \overline{D(R_i)}} \quad . \quad (15)$$

and

$$k = \frac{100\ \phi}{8C} \sum_{i=o}^{n} \frac{v_i\ \overline{R_i^4}}{x_i^2\ \overline{R_i^2}} \quad . \quad (17)$$

In these equations all factors are known or determinable except the factor, x_i, which is proportional to the "effective" capillary length. If the "effective" capillary lengths of all the pores for all samples are the same, the factor, x_i^2, may be written as a "dividing factor", f, in the equations above. The value of f may be shown both theoretically and experimentally for close-packed spheres of uniform size to be $(\pi/2)^{3(2)}$. Since naturally occurring rock structures vary considerably from this ideal "sand" pack, the values of the factors, f, for various permeability ranges apparently can be determined only by experimental measurements. Data obtained by the authors have been plotted with the measured gas permeability versus the "dividing factor" (Fig. 9) that makes the calculated values the same as the measured values. A curve was drawn through the data points to show the general trend. Table IV shows the detailed data used.

An analysis of the data indicates that the factor, f, varies inversely with the permeability of the sample. Since the pores with the smaller radii might be expected to have the more random paths through a porous medium, the factor, f, would be greater for the smaller pores than for those of larger radii. Values of the "effective" capillary lengths were estimated from the accumulated data. These results, the general trend of the "dividing factor" curve, and the probability that the pores of larger radii approach more closely those of the "ideal" sand pack were instrumental in the formulation of the empirical formula

$$x_i = 5\ e^{-0.42 R_i} + 1.83 \quad . \quad . \quad . \quad (18)$$

using the values of x_i determined by this equation permeabilities were calculated (Table V) and plotted against the measured gas permeabilities, Fig. 10, for the samples tested.

It is observed that the calculated permeabilities for five of the samples were low and probably outside the range of experimental error. These samples were taken from a field in which a considerable amount of fine interstitial material was present. Further study and accumulation of data are necessary to verify the empirical Equation (18).

Of special interest are those samples which gave abnormally low or high dividing factor values. A study was made of the distribution curves, Fig. 11, for three samples, the data for two of which deviated from the norm, despite the fact that the measured gas permeabilities of all three were about the same: 20 md. All three of these curves indicated different mean pore entry radii, enclosed different total areas and, therefore, different pore volumes for a chosen radii interval; but the one with the least mean pore entry radius had the largest pore volume, the one with the next larger mean pore entry radius had the second largest pore volume, and the one with the largest mean pore entry radius had the least pore volume. These facts, in conjunction with the variations in dividing factors, explain qualitatively how it is possible for the three samples to have the same permeability, although being widely different structurally.

It is seen from the foregoing that Equations (15) or (17) may be used to calculate the permeability of porous media from pore size distribution data.

Table V

Measured (Gas) Permeability vs. Calculated Permeabilities

FRL Sample No.	Per Cent Porosity	Measured (Gas) Permeability (md)	Calculated* Permeability (md)
13232	20	140	68
686	16	46	98.5
161B	18	6.7	2.9
163A	16	29	20
164B	15	40.8	35.8
164C	18	86.1	71.2
169B	17	29.6	11.6
171C	12	17.1	5.6
171D	10	22	4.4
173C	14	20.1	20.5
173D	14	16	15.8
174B	17	35.5	34.2
174C	17	37.9	35.9
190A	19	93.0	93.7
311A	23	66.6	71.3
311B	18	51.9	63.5
261A	17	0.5	0.2
12618	17	237	245
13996B	20	493	524
15809	20	150	140
6	20	213	264
951	23	179	209
53	20	205	166
682	17	26	23.8

*Used $x_i = 1/R_i$.

Table VI

Physical Measurements of Samples

Sample No.	Gas Permeability (Meas.) md	Run No.	Weight (gms)	No. of Pieces	Surface Area (cm²)	Total Pore Volume Filled (%)	Permeability (Calc.) md
14564	112	1	22.42	1	29.2	85	709
14564	112	2	16.10	Sample	Crushed	84	1240
13302	5.1	1	27.69	1	31.8	68	49.7
13302	5.1	2	26.09	2	40.3	66	56.5
13302	5.1	3	22.61	4	58.0	67	67.2
13302	5.1	4	18.73	16	69.2	64	80.7
174-B	35.5	1	27.28	1	29.8	71	205
		2	15.90	2	21.5	73	244
		3	16.03	4	51.2	79	306

The results of the investigation indicate a reasonably accurate and satisfactory method for permeability measurements. If the permeability is known and the pore size distribution data are available, the lithology factor, f, may be determined by similar equations.

Water Capillary Pressure Determinations

Equation (1), namely,

$$pR_c = -2\sigma\cos\theta$$

may be used to determine capillary pressure curves for "wetting" fluids as well as for "non-wetting" fluids in porous media. The difference lies in the values of the constants, σ and θ. The value of contact angle between the reservoir solid and water was assumed to be that determined between quartz and water. This value, as well as the value of surface tension for the mercury-air interface, was taken from the International Critical Tables. The values so obtained were $\sigma = 72.75$ dynes per cm and $\theta = 0°$.

Using the mercury capillary pressure data (for about ten sandstone samples), water capillary pressure data were calculated by Equation (1), plotted, and compared with the results obtained by the porous diaphragm method. A typical curve is shown in Fig. 12. The porosities of these samples were estimated. Considering the assumptions made and experimental errors involved, the correlations of results are very good. The discrepancies that appear, especially at the extremes of pressures, are under investigation theoretically and experimentally as more data are accumulated.

External Surface Area, Weight, Shape Factor Effects of Samples

In the study of irregularly shaped samples, experimental measurements were made to determine the effect of external surface area, weight, and shape of the sample on the pore size distribution data. This necessitated pore size measurements on a sample and re-runs, on the same sample, with successive changes in one or more of the physical factors. For example, the first run was taken on a sample in one piece and the re-run data were taken with the sample crushed into many pieces. The pressure-volume curves showed increased volume values in the low pressure range for the second run and the calculated permeability was 75 per cent higher than that for the first run.

The procedure for making multiple samples by cutting the originals was altered to make possible plane area measurements, uniform shapes, and constant weights. Physical measurements, calculated permeabilities, and other data are shown in Table VI. A typical set of pressure-volume curves and distribution function curves are shown in Fig. (13) and (14), respectively.

General observation of these data reveal that the volume of mercury penetration in the low pressure range increases as the surface area per unit weight increases, but a quantitative relationship between the two has not been determined. Too, the increase in calculated permeabilities with increase in surface area is erratic and inconsistent and the per cent of pore volume filled by mercury at maximum pressure (1500 psi) varies from run to run for every sample. These variations may be explained partially by the change in effective pore volume when the sample is cut, due either to secluded pores being made available to mercury penetration or to the destruction of pores in the line of cut.

An apparatus was developed to measure the bulk volume of the sample in place in the dilatometer and thus make possible the ultimate determination of the porosity from total imbibed mercury at a pressure of 10,000 psi. This was accomplished by measuring the volume difference to fill the sample chamber with and without the sample. The accuracy of measurement on cylindrical aluminum plugs of known bulk volume was approximately ± 0.1 per cent, whereas reservoir samples gave porosity values consistently higher by this meth-

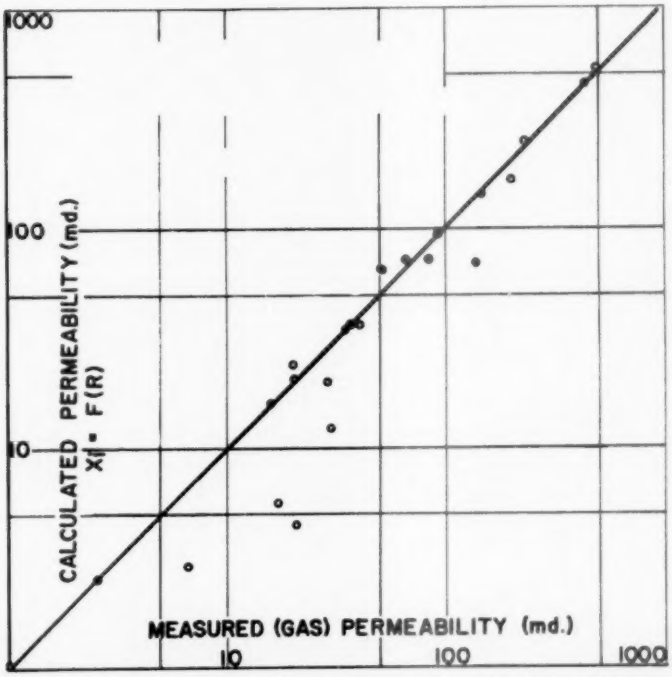

FIG. 10 — PERMEABILITY CALCULATED BY EFFECTIVE CAPILLARY LENGTH VS. MEASURED GAS PERMEABILITY.

od than by independent methods. The apparent increase in porosity was caused by void spaces formed between the sample and the walls of the sample chamber. The effect of such voids on the pressure-volume curves is as if the sample had pores with large radii. Too, the data taken on samples with various surface areas were undoubtedly affected by these and other voids between the sample pieces, to the extent that correlation between the increase in surface area and the increase in calculated permeability was impossible.

CONCLUSIONS

The invesigation of pore entry size distribution in naturally occurring reservoir rocks has involved the development of an apparatus for experimental measurements, the accumulation of pore entry size distribution data on samples taken from various formations, and the derivation of theoretical equations for applications and correlations of the data.

The apparatus is simple to operate, accurate, and reliable. For all practical purposes, the range of data is not limited by the equipment that may be built. For example, the pressure range is now being extended to 10,000 psig with no experimental difficulties anticipated. The operating procedure is straightforward and on a routine basis. The time required for a complete test, starting after preparation of the sample and ending with the calculation of the data and plotting of the curves, is from 3 to 4 hours.

The data obtained from the 100 samples on which this report is based, with the corresponding pressure-volume curves and distribution function curves, represent a cross-section of the type of information to be expected from pore entry size studies of reservoir rocks.

The investigation of the effect of weight, shape, and external surface area of the sample on the data has not been completed. Probably the external surface area effects observed thus far were caused mainly by the apparent pore volume between the sample pieces or between the sample pieces and the walls of the sample chamber. When the apparent pore volume has been eliminated, it is expected that the effect of the shape and external surface area on the measurements will be negligible.

Using the theoretical Equation (17) and the empirical Equation (18), permeabilities can be calculated from pore size distribution data within engineering accuracy, except for rare cases. These equations in conjunction with pore size distribution data are of prime importance in fundamental flow studies of porous media.

The data accumulated so far indicate that water capillary pressure curves may be determined from mercury capillary pressure data taken from small, irregularly shaped samples, with the pressure range greatly exceeding that possible by the porous diaphragm method.

Finally, work is continuing to accumulate more data, to refine the method, and to extend the range of application in the study of porous media.

SYMBOLS

The following definitions are applied to the symbols used in this report:

- σ Surface tension (dynes/cm)
- θ Contact angle (degrees)
- R_i Pore entry radius (cm or microns, $i = 1,2,3 \ldots$)
- p Pressure (cm-Hg, psi, dynes/cm^2)
- $D(R_i)$ Distribution function (cm^2)
- V Volume (cc)
- v_i Incremental volume (fraction of total pore volume)

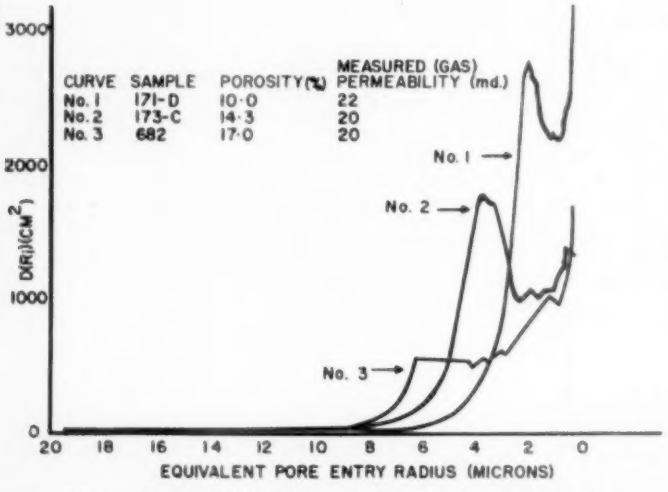

FIG. 11 — EQUIVALENT PORE ENTRY RADIUS VS. DISTRIBUTION FUNCTION.

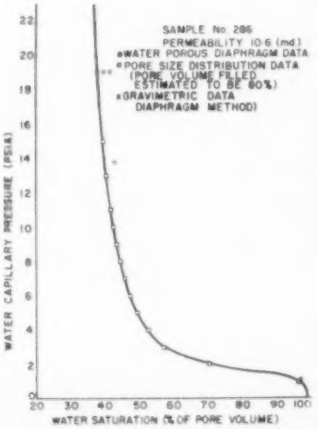
SAMPLE No. 286
PERMEABILITY 10·6 (md.)
WATER POROUS DIAPHRAGM DATA
PORE SIZE DISTRIBUTION DATA (PORE VOLUME FILLED ESTIMATED TO BE 80%)
GRAVIMETRIC DATA DIAPHRAGM METHOD)
WATER CAPILLARY PRESSURE (PSIA)
22 20 18 16 14 12 10 8 6 4 2 0
20 30 40 50 60 70 80 90 100
WATER SATURATION (% OF PORE VOLUME)

FIG. 12 — WATER CAPILLARY PRESSURE CURVE.

V_u Total pore volume (cc)

$\overline{D(R_i)}$ Average distribution function (cm^3)

ΔR Constant pore entry radii interval (cm)

Q Rate of flow (cc/sec)

μ Viscosity (poises, dyne-sec/cm^2)

L Length of sample (cm)

n_i Number of pores in the range ΔR

n Number of terms included in sum

k Permeability (darcys)

ϕ Porosity (fractional)

C Conversion constant (9.87×10^{-9} atmos/dynes/cm^2)

f Dividing factor

L_i "Effective" capillary length (cm)

x_i Proportionality factor (ratio of L_i to L)

A Area of cross-section of sample (cm^2)

k_g Measured gas permeability (darcys)

v_p pore volume (cc)

v_{ms} Total volume of pore space filled by mercury (cc)

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APPENDIX

The rate of flow of a fluid through a single capillary is according to Poiseuille's Equation

$$\frac{Q\mu}{\Delta p} = \frac{\pi R_i^4}{8L} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The equivalent expression for the rate of flow of a fluid through an assemblage of parallel capillaries, each of the same length but having varying values of radius, is

$$\frac{Q\mu}{\Delta p} = \frac{\pi}{8L} \sum_{i} n_i \overline{R_i^4 \rightarrow_{i+x}} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where

$$\overline{R_i^4} = \sum_{i}^{i+x} \frac{R_i^4 \rightarrow_{i+x}}{n}$$

and n_i is the number of pores in the range ΔR.

Now,

$$\phi = \frac{\pi}{A} \sum_{i} n_i \overline{R_i^2 \rightarrow_{i+x}} \quad . \quad . \quad . \quad . \quad (5)$$

where ϕ is the fractional porosity, A is the area of cross-section, and

$$\overline{R_i^2} = \sum_{i}^{i+x} \frac{R_i^2 \rightarrow_{i+x}}{n}$$

$$\therefore \frac{Q\mu}{\Delta p} = \frac{\pi}{8L} \sum_{i=o}^{n} \left[n_i \sum_{i}^{i+x} \frac{R_i^4}{n} \right] \quad . \quad . \quad (6)$$

$$\phi = \frac{\pi}{A} \sum_{i=o}^{n} \left[n_i \sum_{i}^{i+x} \frac{R_i^2}{n} \right] \quad . \quad (7)$$

Instead of assuming that the capillaries have equal lengths consider each radii interval with an "effective" capillary length, L_i. Also, let

$$L_i = x_i L \quad . \quad . \quad . \quad . \quad (8)$$

Then Equation (6) becomes

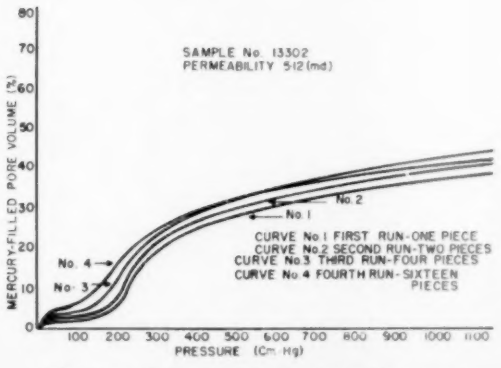

FIG. 13 — MERCURY IMBIBITION CURVES; MERCURY FILLED PORE VOLUME VS. PRESSURE.

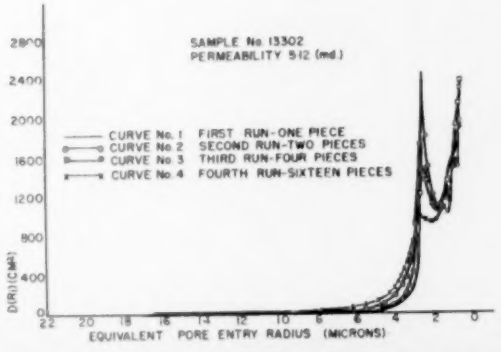
SAMPLE No. 13302
PERMEABILITY 512 (md.)
CURVE No. 1 FIRST RUN-ONE PIECE
CURVE No. 2 SECOND RUN-TWO PIECES
CURVE No. 3 THIRD RUN-FOUR PIECES
CURVE No. 4 FOURTH RUN-SIXTEEN PIECES
DIFFERENTIAL
EQUIVALENT PORE ENTRY RADIUS (MICRONS)

FIG. 14 — EQUIVALENT PORE ENTRY RADIUS VS. DISTRIBUTION FUNCTION.

$$\frac{Q\mu}{\Delta p} = \frac{\pi}{8L} \sum_{i=o}^{n} \left[\frac{n_i}{x_i} \sum_{i}^{i+x} \frac{R_i^4}{n} \right] \quad . \quad (9)$$

Similarly,

$$\phi = \frac{\pi}{A} \sum_{i=o}^{n} \left[x_i n_i \sum_{i}^{i+x} \frac{R_i^2}{n} \right] \quad (10)$$

Also, the rate of flow through this same system is given by Darcy's Law:

$$\frac{Q\mu}{\Delta p} = \frac{CA}{100L} \cdot k \quad . \quad (11)$$

where k is the permeability in darcys. Combining Equations (9), (10), and (11) gives

$$k = \frac{100\ \phi}{8C} \frac{\sum_{i=o}^{n} \left[\frac{n_i}{x_i} \sum_{i}^{i+x} \frac{R_i^4}{n} \right]}{\sum_{i=o}^{n} \left[x_i n_i \sum_{i}^{i+x} \frac{R_i^2}{n} \right]} \quad . \quad (12)$$

By definition

$$v_i = \overline{D(R_i)} \cdot \Delta R = \pi x_i L \sum_{i}^{i+x} \frac{n_i R_i^2}{n} \quad . \quad (13)$$

where v_i is the fractional of total pore volume in the radii interval R_i to R_{i+x}.

$$\therefore n_i = \frac{\overline{D(R_i)}\ \Delta R}{\pi x_i L \sum_{i}^{i+x} \frac{R_i^2}{n}} \quad (14)$$

Substituting Equation (14) in (12),

$$k = \frac{100\ \phi}{8C} \frac{\sum_{i=o}^{n} \frac{\overline{D(R_i)}\ \overline{R_i^4}}{\overline{x_i^2}\ \overline{R_i^2}}}{\sum_{i=o}^{n} \overline{D(R_i)}} \quad . \quad (15)$$

Also, from Equation (13)

$$n_i = \frac{v_i}{\pi x_i L \sum_{i}^{i+x} \frac{R_i^2}{n}} \quad . \quad (16)$$

Combining Equations (16) and (12)

$$k = \frac{100\ \phi}{8C} \sum_{i=o}^{n} \frac{v_i \overline{R_i^2}}{\overline{x_i^2}\ \overline{R_i^2}} \quad (17)$$

* * *

T.P. 2912

THE SP LOG IN SHALY SANDS

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ABSTRACT

As a continuation of the earlier paper on the general subject of the SP log, a more complete analysis of certain features of the SP log in shaly sands is given. The pseudo-static SP in front of shaly sands is compared, on a theoretical basis, to the static SP in front of clean sands, as a function of the respective amount of shale and sand in the formation, and of the relative resistivities of the shale, of the uncontaminated part of the sand, and of the invaded zone of the sand.

As a conclusion, the advantage of using reasonably conductive mud in this case is shown.

The discussion is illustrated by field examples.

INTRODUCTION

The discussion reported in the present paper is based on a theoretical analysis, and not on experiment. The field examples, joined to the text, are shown only as qualitative illustrations of the essential results of this analysis. Although the hypotheses made in the theoretical developments may perhaps be somewhat improved, it seems, nevertheless, that the results obtained account reasonably well for the actual phenomena, and give a fair approximation of their order of magnitude.

The paper contains a mathematical analysis of a tri-dimensional distribution of potentials and current lines, due to spontaneous electromotive forces arising at the contact of shales and free electrolytes, as a function of the geometry and of the respective resistivities of the different media involved. It is assumed, although this hypothesis is not proven, that the emf's remain the same even if the shale occurs in very thin layers or in dispersed particles.

It has already been pointed out[1,2,3] that, all other conditions being the same, the deflection of the SP log in front of a shaly sand is smaller than opposite a clean sand. When the thickness and the conductivity of a clean sand are large enough, the deflection of the SP log reaches a limiting value which is equal to the "static SP" of the clean sand. It is generally convenient to take the static SP of shale as the reference value or "base line." As a consequence, and for the sake of abbreviation, the expression, "static SP of a clean sand," is often used to designate the difference between the static SP of that sand and that of the shales, which difference is a measure of the total electromotive forces involved in the chain mud sand-shale.

A similar limiting value is also observed for the SP deflection opposite a thick shaly sand, but it is smaller, just as if the total electromotive force involved were smaller in that case. This limiting value has been called the "Pseudo-Static SP" of the shaly sand.

The static SP of a clean sand depends on the salinity of its connate water with respect to that of the mud, and, to a certain extent, on the differential pressure which controls the electro-filtration potentials, but it does not depend on the resistivity of the sand. On the contrary, the pseudo-static SP of a shaly sand depends not only on the salinity of its connate water and on the differential pressure, but also on the percentage of shale and on the resistivities of the shale, of the uncontaminated part of the sand, and of the zone invaded by the mud filtrate.

If the three resistivities above were equal, the pseudo-static SP would be proportional to the percentage of sand in the shaly sand, and its departure from the static SP of a clean sand having the same connate water would simply be proportional to the percentage of shale. In that case, the pseudo-static SP of a shaly sand containing 10 per cent of shale would be 10 per cent less than the static SP of a clean sand.

When, however, the sand is, on the average, substantially more resistive than the shale, the percentage of departure of the pseudo-static SP from the static SP of a clean sand is much larger than the percentage of shale. For that reason, the peaks of the SP log opposite shaly sands are systematically of smaller amplitude when the sands are oil-bearing than when they are water-bearing, all other conditions being the same. This feature is observed even when the sand beds are thick, and even when they do not contain a large percentage of shale.

All this has already been described in an earlier publication[3], but mostly in a qualitative way. The present paper will analyze in more detail the action of the local SP currents which are generated inside of the shaly sands, and which are responsible for the abnormally low value of the pseudo-static SP. The quantitative computations have been extended to the general case of thin interbedded layers of sand and shale, where the resistivities of the shale and sand streaks do not have the same value; they are summarized in charts giving values of the pseudo-static SP of a shaly sand as a function of the different parameters involved.

DEFINITIONS

The static SP of a clean sand has been defined as the potential that would exist in the mud opposite that sand, were the SP current prevented from flowing. Such an ideal condition is represented on Fig. 1-A.

By analogy, the pseudo-static SP of a shaly sand can be defined as the potential that would exist in the hole, if the circuit shaly sand — surrounding shales — mud column were interrupted by the insulating plugs placed at the boundaries

[1] References are given at end of the paper.

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between the shaly sand and the surrounding shales, as represented in Fig. 1-B, in which it is assumed that the connate water in the invaded zone has been completely displaced by the mud filtrate, and that there are no electromotive forces between the mud column and the invaded zone in the sand layers. Under these conditions, the potential in the mud corresponds to the diagram represented in solid line, and the pseudo-static SP is, as defined, the average value of the potential opposite the shaly sand (i.e., disregarding the ripples, which, in fact, are negligible if the individual beds of sand and shale are thin enough).

It must be remarked that in Fig. 1-B, the insulating plugs interrupt only the circuit of the SP current which normally would flow into the shaly sand, from the shaly sand into the surrounding shales, and back from the surrounding shales through the mud column and the invaded zone. This SP current should be differentiated from local currents whose whole paths are small and remain inside of the shaly sand itself. The former will be referred to as the "external SP current" (dashed lines on Fig. 1-B), the latter as the "internal SP current" (solid lines on Fig. 1-B). Under normal conditions, i.e., in the absence of insulating plugs, the external SP current is free to flow and produces in the mud column, by ohmic effect, the potential differences which are recorded on the SP log (dashed diagram, Figs. 1-A and 1-B).

The internal SP currents represented on Fig. 1-B, and which flow from the invaded zone of each sand streak into its uncontaminated part, and back through the surrounding shale streaks, are generated in exactly the same way as the external SP currents, because of the existence of the electrolytic chain mud filtrate — connate water — shale. These internal currents produce potential differences by ohmic effect both in the shale streaks and in the sand streaks, and the respective values of these ohmic drops of potential, in the shale parts and in the sand parts of their circuit, determine the value of the pseudo-static SP, as explained later on.

QUANTITATIVE ANALYSIS OF THE PSEUDO-STATIC SP IN SHALY SANDS

The following assumptions will be made:

1. The shaly sands are thick and are constituted of alternating sequences of pure thin sands and pure thin shales.
2. In a given shaly sand, all the thin sand beds are identical and have the same thickness h, whereas all the thin shale beds are also identical and have the same thickness h', so that the average proportion of sand and shale is the same at all levels.
3. The individual thicknesses, h, of the sand beds, and, h', of the shale beds are both small in comparison with the diameter of the hole.
4. The depth of penetration of the mud filtrate into the individual sand beds is large in comparison with their thicknesses.
5. The effect of the electrofiltration potentials can be neglected* and there is no other electromotive force across the mud cake.

For reasons of convenience, the following cases will be considered in succession:

(a) Shaly sand with 50 per cent sand and 50 per cent shale, in which there is no diffusion between the mud filtrate and the connate water. This is an ideal case in which the thickness of the sand beds is supposed to be the same as that of the shale beds. Moreover, in the sands the zone which is invaded by the mud filtrate, and the uncontaminated zone, are both considered to be homogenous, and to make a sharp contact with each other.

(b) Shaly sand with 50 per cent sand and 50 per cent shale, with diffusion between mud filtrate and connate water, and with a continuous variation in the oil saturation throughout the invaded zone.

(c) Shaly sand in which the thickness of the sand beds is not the same as that of the shale beds, also with diffusion and a continuous variation of the oil saturation.

Shaly Sands with 50 Per Cent Shale, 50 Per Cent Sand and No Diffusion

This case is, of course, of a purely theoretical nature, but it is very useful to consider it as a first step in the analysis. Fig. 2 represents a very thick shaly sand of that category, and shows schematically the internal currents which flow in each sand bed from the invaded zone — supposed to be homogeneous — into the uncontaminated zone, and back

*This effect is analyzed in another paragraph at the end of the paper.

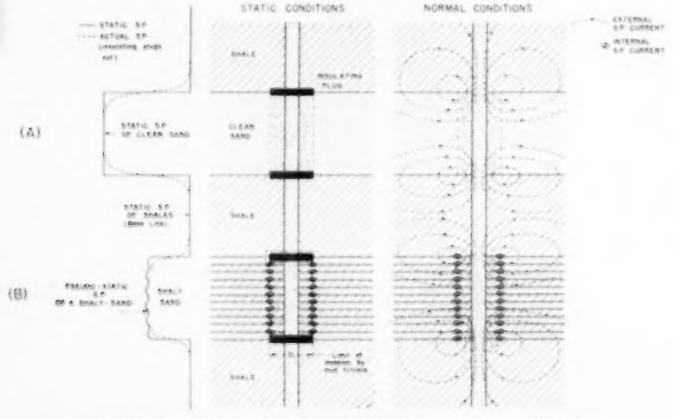


FIG. 1A — SCHEME OF STATIC AND NORMAL CONDITIONS, CLEAN SAND.
1B — SCHEME OF STATIC AND NORMAL CONDITIONS, SHALY SAND.

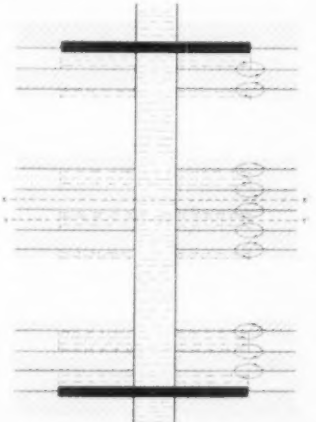


FIG. 2 — PSEUDO-STATIC CONDITION.

through the adjoining shale beds. By reason of symmetry, no line of current flow crosses the planes like XX' or YY' which divide any of the beds into equal parts. Nothing is changed, therefore, in the space between planes XX' and YY', from the point of view of the current and potential distribution, if all the surrounding formations are removed in order to isolate the two half beds. The case of the shaly sand represented in Fig. 2 can, therefore, be reduced to that of two adjoining beds, respectively of sand and shale, and both in contact with the mud, as represented in Fig. 3.

In Fig. 3-A it is assumed that an insulating plate is preventing the internal SP current from flowing. The potential is arbitrarily taken equal to zero at all points in the shale bed which are far enough from the mud column so that the SP current has no influence on their potential. In that case, the potentials in the different regions have the values indicated in rectangular frames in Fig. 3-A, namely:

Zero in the shale,
$V_o = +c$ in the mud opposite the shale,
$-b$ in the uncontaminated sand,
$-a-b = V_o - (a+b+c)$ in the mud opposite the sand, and in the invaded zone.

(This last expression has been placed in Fig. 3-A in a rectangle which covers both the mud and the invaded zone, because the potential is the same in these two regions, it being assumed that there is no electromotive force across the mud cake.)

In these expressions:

a is the boundary emf between mud filtrate and connate water,

b is the boundary emf between connate water and shale,

c is the boundary emf between shale and mud or mud filtrate.

When the insulating plate is removed, the internal SP current flows as schematically represented in Fig. 3-B, and produces potential drops by ohmic effect in the shale and in the sand. These potential drops have been designated by PD_{sh}, PD_i and PD_t respectively for the shale bed, the invaded zone, and the uncontaminated sand. The potential in the mud — that is the pseudo-static SP — can be computed by considering the ohmic drops and the boundary emf's encountered when following a path from the shale in the direction toward the hole, either along the shale bed or along the sand bed.

In the first case, the value obtained is expressed by:

$$-PD_{sh} + c$$

In the second case, the expression is:

$$-b + PD_t - a + PD_i$$

This second expression has also been placed in Fig. 3-B in a rectangle which covers both the mud and the invaded zone.

The two expressions above are identical with the assumptions made, because the total drop of potential along the path of the internal current i must be equal to the total electromotive force involved, or

$$PD_{sh} + PD_t + PD_i = a + b + c$$

so that:

$$-PD_{sh} + c = -b + PD_t - a + PD_i$$

Under the hypothesis made that the potential is zero at a great distance inside the shale, $+c$ represents the static SP of the shales, whereas $(-a-b)$ represents the static SP of clean sands, having the same connate water. The pseudo-static SP can, therefore, be written in either of two ways:

Pseudo-static SP = Static SP of shales $- PD_{sh}$

or

Pseudo-static SP = Static SP of clean sands $+ PD_t + PD_i$

A shaly sand can, therefore, be considered as a shale in which internal currents due to sand streaks create potential drops that make its pseudo-static SP more negative than that of a pure shale. It can also be considered as a sand in which internal currents due to the presence of shale streaks create potential drops that make its pseudo-static SP more positive than that of a clean sand. Both definitions are equivalent, and this illustrates once more the symmetrical character of the SP log with respect to sand and shales, and more generally, with respect to impervious and permeable beds.

It remains to evaluate quantitatively the values of PD_{sh}, or of PD_i and PD_t, as functions of the different resistivities of the three media.

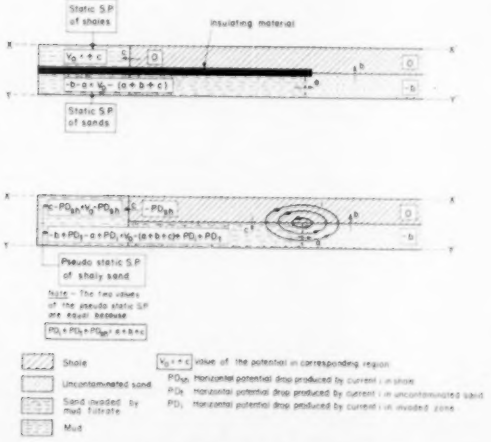

Static S.P of shales
Insulating material
Static S.P of sands
Pseudo static S.P of shaly sand
Note – The two values of the pseudo static S.P are equal because
Shale
Uncontaminated sand
Sand invaded by mud filtrate
Mud
value of the potential in corresponding region
Horizontal potential drop produced by current i in shale
Horizontal potential drop produced by current i in uncontaminated sand
Horizontal potential drop produced by current i in invaded zone

FIG. 3A — THEORETICAL STATIC CONDITIONS.
3B — PSEUDO-STATIC CONDITIONS.

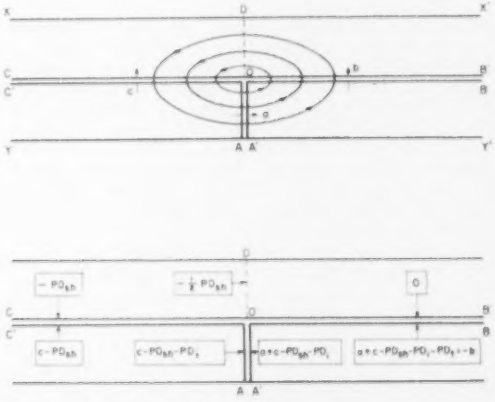


FIG. 4A — BOUNDRY EMF's AND LINES OF RESULTING CURRENT FLOW.

4B — POTENTIALS EXISTING IN THE SEPARATE ZONES.

Computation of PD_{sh}, PD_i and PD_t

When the depth of penetration of the mud filtrate in the sand streaks is large in comparison with their thickness, the internal SP current, which flows essentially in the vicinity of the boundary between the invaded zone and the uncontaminated zone, does not reach the mud column. On the other hand, that boundary can be likened to a plane, even though it actually is a cylinder, since its radius of curvature is large in comparison with the thickness of the individual layers of sand and shale. It is therefore sufficient to study the simplified case represented in Fig. 4-A and Fig. 4-B, where there are only three media separated by plane surfaces which are perpendicular to the plane of the figure, and to compute PD_{sh}, PD_i and PD_t for that case.

In Fig. 4-A, the boundaries between the different media have been represented by double lines to illustrate the fact that there is an electromotive force at each boundary and, therefore, a constant potential difference between the two sides of the same boundary.

In Fig. 4-B, the values of the potentials prevailing in the shale and in the sand, at great distances from the hole, near to the boundary of the invaded and uncontaminated zones, and close to the hole, have been placed in rectangular frames.

When the three resistivities R_{sh}, R_i and R_t are equal, the figure has two planes of symmetry *DOA* and *COB*. This same symmetry, therefore, applies to the lines of current flow which are represented in Fig. 4-A by solid lines with arrows. These lines of current flow across the boundaries, and also across the plane *DO*, perpendicularly. Either side of any boundary is, therefore, an equipotential surface, and there is a potential difference equal to the boundary emf between the two sides of that boundary.

By reason of symmetry, the resistance between the equipotential planes *OB'* and *OD* is equal to that between *OD* and *OC*, and to those respectively between *OC'* and *OA*, and between *OA'* and *OB*. If r is one of these resistances, i the intensity of the current, g a geometrical factor which is a function of the thickness of the individual layers, and R the common resistivity of the three media, one can write:

$$PD_{sh} = i \times 2r = i \times 2gR$$
$$PD_i = i \times r = i \times gR$$
$$PD_t = i \times r = i \times gR$$

If now the resistivities of the three homogeneous media are made different from each other, and respectively equal to R_{sh}, R_i and R_t, the lines of current are not changed, and the resistances in the different sectors respectively become gR_{sh}, gR_i and gR_t. The intensity of the current is changed, because of the change in the total resistance of the circuit. The shape of the equipotential surfaces, whether at the boundaries or elsewhere, remains unchanged, but the potential of each of these equipotential surfaces is changed. The new values of the potential drops in the three media are given by:

$$PD_{sh} = i \times 2gR_{sh}$$
$$PD_i = i \times gR_i$$
$$PD_t = i \times gR_t$$

and since the total potential drop must be equal to the total electromotive force along the circuit:

$$PD_{sh} + PD_i + PD_t = a + b + c = E$$

From the above relations, it is easy to deduce:

$$-PD_{sh} = -E\frac{2R_{sh}}{2R_{sh} + R_i + R_t} \quad \ldots\ldots\ldots \quad (1)$$

and

$$PD_i + PD_t = E\frac{R_i + R_t}{2R_{sh} + R_i + R_t} \quad \ldots\ldots\ldots \quad (2)$$

which give respectively the pseudo-static SP with respect to the static SP of shales (base line), and the departure of the pseudo-static SP with respect to the static SP of a clean sand.

It is interesting to consider the ratio α of the pseudo-static SP of a shaly sand to the static SP of a clean sand with, of course, the same connate water. These two quantities are respectively equal to $-PD_{sh}$ (Eq. 1) and to $-E$, so that their ratio α is given by:

$$\alpha = \frac{\text{pseudo-static SP shaly sand}}{\text{static SP clean sand}} = \frac{1}{1 + \dfrac{R_i + R_t}{2R_{sh}}} \quad . \quad (3)$$

The coefficient α is called the "reduction factor."

Relation (3) applies only to the present case of a shaly sand with 50 per cent sand, 50 per cent shale and no diffusion in the invaded zone.

The exact distribution of the potentials and of the current lines, established through computations, is given in Fig. 5. This figure demonstrates that, at reasonable distances from the boundary between mud filtrate and uncontaminated sand, the potentials in the shale are on either side respectively equal to zero and $-PD_{sh}$.

Shaly Sand with 50 Per Cent Shale, 50 Per Cent Sand and with Diffusion in the Invaded Zone

This condition can be treated by assuming the diffusion occurs in steps, as represented in Fig. 6. If it is furthermore supposed that the diffusion takes place over a distance great in comparison with the individual thickness of each shale or sand bed, the invaded zone can be divided into a sequence of homogeneous sections with respective resistivities R_1, R_2, R_3, . . . , such that the length of each section, measured along the stratification, is much greater than its height, measured in the perpendicular direction. If $E_{1,2}$, $E_{2,3}$, $E_{3,4}$, . . . , are the total electromotive forces involved at each of the successive boun-

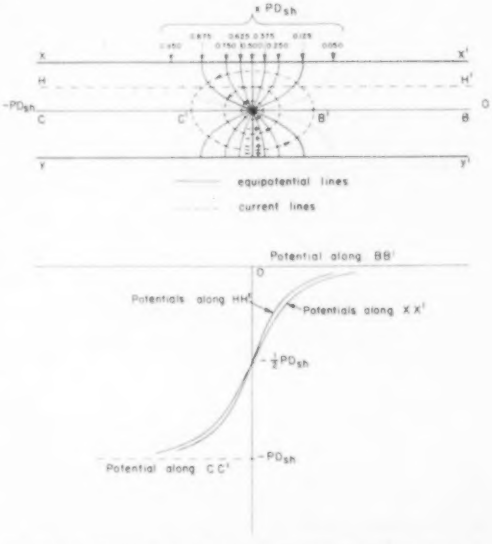


FIG. 5 — DISTRIBUTION OF EQUIPOTENTIALS AND CURRENT LINES (COMPUTED).

daries between these sections, the total potential drop along the shale is given by:

$$PD_{sh} = E_{1\cdot2}\frac{1}{1+\frac{R_1+R_2}{2R_{sh}}} + E_{2\cdot3}\frac{1}{1+\frac{R_2+R_3}{2R_{sh}}} + \ldots$$

It is convenient to replace this summation with an integral:

$$PD_{sh} = \int_l^L E(x)\frac{1}{1+\frac{R(x)}{R_{sh}}}dx \qquad (4)$$

in which:

$E(x)$ is the electromotive force per unit length along the shaly sand, prevalent at the radial distance x from the axis of the hole.

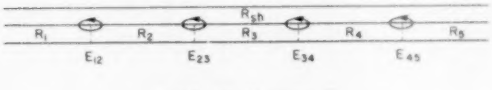
$R(x)$ is the resistivity of the invaded zone at the radial distance x.

l and L are the radial distances of the two limits of the invaded zone.

The value of $E(x)$ at any radial distance is proportional to the relative change of salinity per unit length at that radial distance. If $R_w(x)$ designates the resistivity of the water in the sand at the radial distance x, the value of $E(x)$ is given by:

$$E(x) = -K'\frac{\frac{dR_w(x)}{dx}}{R_w(x)} \qquad (5)$$

so that the general expression for PD_{sh} becomes:



$$E_{12} + E_{23} + E_{34} + \cdots\cdots = E$$

FIG. 6 — ILLUSTRATION OF CONCEPT OF DIFFUSION INCREMENTS.

$$PD_{sh} = -K'\int_l^L \frac{\frac{dR_w(x)}{dx}}{R_w(x)}\frac{1}{1+\frac{R(x)}{R_{sh}}}dx \qquad (6)$$

It is interesting to consider the case where the diffusion follows an exponential law, as would seem natural. In that case, one must have:

$$R_w(x) = R_{wf}\left(\frac{R_w}{R_{wf}}\right)^{\frac{x-l}{L-l}} \qquad (7)$$

where R_w and R_{wf} are the resistivities of the connate water and of the mud filtrate.

Relations (5) and (7) give:*

$$E(x) = -K'\frac{L_n\frac{R_w}{R_{wf}}}{L-l} = K\frac{\log\frac{R_{wf}}{R_w}}{L-l} \qquad (8)$$

The expression for PD_{sh} given by equation (6) then becomes:

$$PD_{sh} = \frac{K\log\frac{R_{wf}}{R_w}}{L-l}\int_l^L \frac{dx}{1+\frac{R(x)}{R_{sh}}} \qquad (9)$$

$(-PD_{sh})$ is the value of the pseudo-static SP, referred to the static SP of shales, and can be computed through equation (9) as a function of the different resistivities within the sand streaks. In particular, when the resistivity of the sand varies from a value R_i, at the beginning of the zone of diffusion radial distance l), to a value R_t at the end of that zone (radial distance L), and this according to an exponential law, $R(x)$ is given by the expression:

$$R(x) = R_i\left(\frac{R_t}{R_i}\right)^{\frac{x-l}{L-l}} \qquad (10)$$

and, after reduction, the expression for PD_{sh} becomes:

$$PD_{sh} = K\log_{10}\frac{R_{wf}}{R_w}\left(1-\frac{\log\frac{R_i+R_{sh}}{R_t+R_{sh}}}{\log\frac{R_i}{R_t}}\right) \qquad (11)$$

so that:

$$\alpha = \frac{\text{Pseudo-static SP of shaly sand}}{\text{Static SP of clean sand}} = 1-\frac{\log\frac{R_i+R_{sh}}{R_t+R_{sh}}}{\log\frac{R_i}{R_t}} \qquad (12)$$

which, after transformation and with simplified notations, can be written:

$$\alpha = \frac{\log\frac{u+q}{1+q}}{\log u} \qquad (13)$$

where

$$u = \frac{R_i}{R_t} \qquad q = \frac{R_t}{R_{sh}}$$

This expression applies to a shaly sand with 50 per cent sand, 50 per cent shale, in which both the salinity and the resistivity in the invaded zone vary exponentially with the radial distance from the axis of the hole.

*The present mathematical development implies that the electro-chemical SP is related to mud resistivity and connate water resistivity by an expression such as $SP = K\log\frac{R_{wf}}{R_w}$.

$u = \frac{R_i}{R_t}$ — Mud Factor

$q = \frac{p}{1-p}\frac{R_t}{R_{sh}}$ — Conductance Ratio

$\alpha = \frac{\text{Pseudo-Static S.P. Shaly Sand}}{\text{Static S.P. Clean Sand}}$ — Reduction Factor

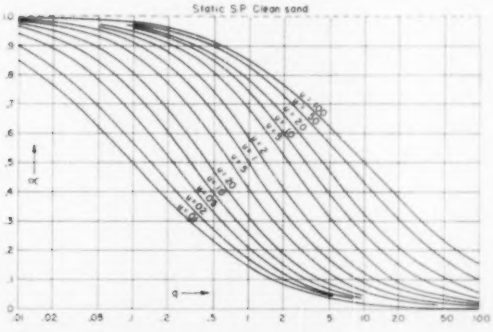


FIG. 7

Shaly Sand in Which the Thickness of the Sand Beds is Not the Same as That of the Shale Beds

The formulae established in the previous section, for shaly sands having 50 per cent of shale and 50 per cent of sand, can be extended to the case where the proportion of sand and shale has any given value. Without going through the demonstration, and in order not to extend the discussion, it can simply be stated that the expressions 9, 11 and 12 above can be used to compute PD_{sh} and a in the general case, provided that R_{sh}, R_t, R_i be respectively replaced by $\frac{R_{sh}}{p}$, $\frac{R_t}{1-p}$ and $\frac{R_i}{1-p}$, p being the proportion of shale, and, consequently, $(1-p)$ the proportion of sand, in the shaly sand. With this change, expressions (9) and (13), for example, will read for the general case, after making obvious simplifications:

$$PD_{sh} = \frac{K \log \frac{R_{mf}}{R_w}}{L-l} \int_l^L \frac{dx}{1 + \frac{p}{1-p}\frac{R(x)}{R_{sh}}} \quad . \quad . \quad . \quad (14)$$

and

$$a = \frac{\text{Pseudo-static SP shaly sand}}{\text{Static SP clean sand}} = \frac{\log \frac{u+q}{1+q}}{\log u} \quad . \quad (15)$$

with

$$u = \frac{R_i}{R_t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

$$q = \frac{p}{1-p}\frac{R_i}{R_{sh}}$$

p = proportion of shale in the shaly sand.

PRACTICAL APPLICATION — CHARTS

Expression (15) has been used to compute the chart of Fig. 7. This chart gives the pseudo-static SP of a shaly sand as compared to that of a clean sand having the same connate water. To use the chart, it is necessary to determine for each particular case the two quantities:

$$u = \frac{R_i}{R_t}$$

and

$$q = \frac{p}{1-p}\frac{R_i}{R_{sh}}$$

in which:

p is the proportion of shale.

R_i is the resistivity of the sand streaks in the uncontaminated zone.

R_t is the resistivity of the sand streaks in the invaded zone, immediately behind the mud cake.

R_{sh} is the resistivity of the shale streaks.

u represents the relative influence of R_t, which is a direct function of mud resistivity, which consequently, may be called the "mud factor."

q represents the ratio of the respective contributions of the shale and sand streaks to the horizontal conductivity of the shaly sand in its uncontaminated zone. It may therefore be referred to as the "conductance ratio."

This chart applies to all cases where both the salinity and the resistivity in the sand streaks vary exponentially through the invaded zone. It can be demonstrated that the chart also applies to shaly sands that contain no oil, whatever the law of variation of salinity through the invaded zone, provided that the variation of salinity be continuous, i.e., without large changes occurring over radial distances which are small in comparison with the individual thickness of the individual layers of sand and shale.

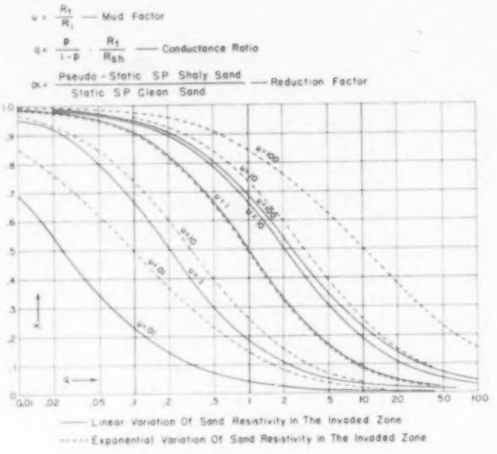

u = Rt/Ri — Mud Factor
q = p/(1-p) · Ri/Rsh — Conductance Ratio
a = Pseudo-Static SP Shaly Sand / Static SP Clean Sand — Reduction Factor
u=20
u=10
u=5
u=2
u=1
u=0.5
u=0.2
u=0.1
q
0.01 .02 .05 .1 .2 .5 1 2 5 10 20 50 100
Linear Variation Of Sand Resistivity In The Invaded Zone
Exponential Variation Of Sand Resistivity In The Invaded Zone

FIG. 8

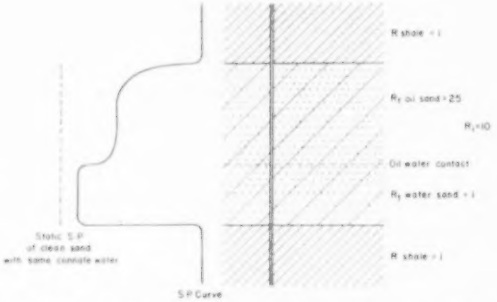

R shale = 1
Rt oil sand = 25
Ri=10
Oil-water contact
Rt water sand = 1
R shale = 1
Static S.P. of clean sand with same connate water
S.P Curve

FIG. 9 — SHALY SAND WITH 4 PER CENT SHALE; OIL BEARING AT THE TOP AND WATER BEARING AT THE BOTTOM (COMPUTED CURVE).

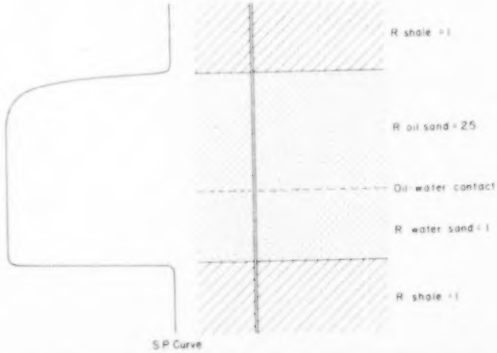


FIG. 10 — CLEAN SAND; OIL BEARING AT THE TOP AND WATER BEARING AT THE BOTTOM (COMPUTED CURVE).

In the case of an oil sand where the resistivity varies linearly instead of exponentially,* in the invaded zone, the value of α is smaller than that indicated on the chart. This is illustrated by Fig. 8, on which a few curves computed for the linear law are compared to the corresponding curves for the exponential law extracted from chart of Fig. 7.

Example: An oil-bearing shaly sand, with 20 per cent shale, is considered, where:

R_{sh} = 1 ohm-m — Resistivity of shale
R_t = 25 ohm-m — Resistivity of uncontaminated sand
R_w = .1 ohm-m — Resistivity of connate water
R_m = 2 ohm-m — Resistivity of mud
Formation factor = 10

*Of course, the law of variation of resistivity in the invaded zone is not exactly known, and has been here taken linear chiefly as a simple example.

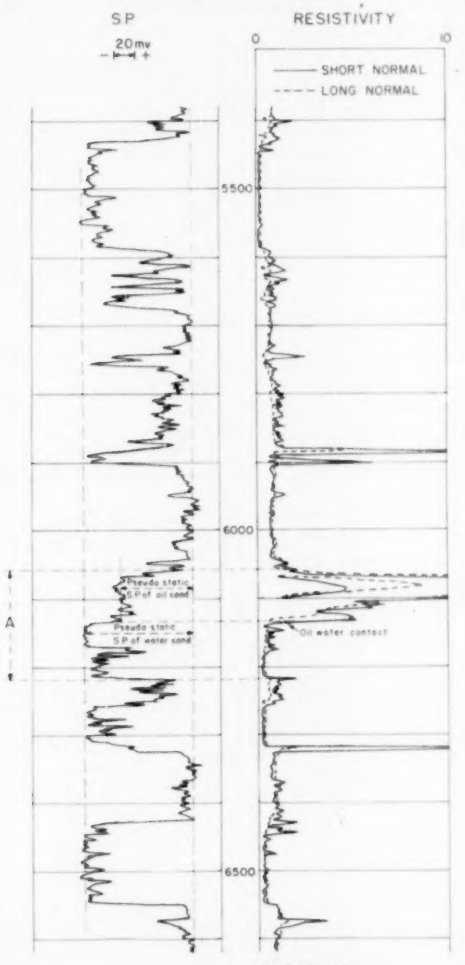


FIG. 11 — FIELD EXAMPLE OF SP LOG IN SHALY SAND.

Hence:
a = 1.25 — mud factor
q = 6.2 — conductance ratio
Chart of Fig. 7 gives:
α = .15 — Reduction factor.

Pseudo-Static SP of Water Sands and Oil Sands

The pseudo-static SP of a shaly sand is of smaller magnitude if that sand is oil-bearing, than if it is water-bearing, because in the first case, R_t is much larger and affects the conductance ratio q accordingly. This is the reason why sands, which are seldom quite clean, frequently show less SP deflection opposite their oil-bearing section than opposite their water-bearing section. This is illustrated by Fig. 9 which represents a computed SP log for a thick, shaly sand, partly oil-bearing, partly water-bearing. It is interesting to compare this theoretical log with that of a clean sand, having otherwise exactly the same characteristics, namely the same connate water and the same saturation (Fig. 10).

It should be pointed out that the proportion of shale in a shaly sand is seldom constant throughout the whole bed. In particular, the percentage of shale generally decreases from the top and bottom boundaries towards the center of the bed. In the case of water-bearing sands, the pseudo-static SP is little different from the static SP of clean sands, and therefore is affected little by the variation of the shale content. On the contrary, the pseudo-static SP of oil-bearing sands is very sensitive to the proportion of shale. In practice, the shape of the SP curve, at the level of the boundaries of an oil-bearing bed, is therefore smoother for a shaly sand than for a clean sand, all other conditions being the same. Also, the SP curve generally does not involve a plateau opposite thick oil-bearing shaly sands, but more often shows fluctuations according to the variations of the pseudo-static SP, i.e., of the percentage of shale.

Field Examples

Fig. 11 is a practical example of SP log opposite a sequence of shales and shaly sands. For the sake of completeness, the resistivity curves, recorded with both the short and the long normal devices, have been reproduced on the figure. On this example, all the water-bearing sands of sufficient thickness show the same pseudo-static SP. Bed (A), is oil-bearing at the top, water-bearing at the bottom. The pseudo-static SP opposite the oil-bearing part is strikingly less than the pseudo-static SP of the water-bearing sands. Moreover, the shape of the average contour of the peak, opposite bed (A), is quite similar to that of the theoretical curve, Fig. 9.

Fig. 12 illustrates the case of a clean sand, and should be compared to Fig. 10.

Fig. 13 shows the logs obtained opposite the same shaly sand, in two different bore holes. In one hole, the sand is oil-bearing, and the pseudo-static SP is equal to 20 mv; in the other, the sand is water-bearing, and the pseudo-static SP is equal to 50 mv.

Computation of the Resistivity of the Connate Water from the Pseudo-Static SP of a Shaly Sand

It has been proposed[4,5,7] to compute the resistivity R_w — and, therefore, the salinity — of the connate water in a sand from the static SP by the formula:

$$E = K \log_{10} \frac{R_{mf}}{R_w} \qquad (17)$$

in which E is the absolute value of the static SP, corrected for the electrofiltration potential, if that quantity is not negligible, R_{mf} is the resistivity of the mud filtrate, and K is a

coefficient theoretically equal to approximately 70 when E is expressed in millivolts (4). This relation can also be written:

$$\log R_w = \log R_{mf} - \frac{E}{K} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

In the case of a thick shaly sand, the pseudo-static SP, as determined from the log, is equal to αE, and instead of R_w, the formula gives a false value R_{w_a}, such that:

$$\log R_{w_a} = \log R_{mf} - \alpha\frac{E}{K} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (19)$$

By combined relations (18) and (19), the following relation is obtained:

$$\log \frac{R_{w_a}}{R_w} = (1-\alpha)\frac{E}{K} = (1-\alpha)\log \frac{R_{mf}}{R_w} \quad . \quad . \quad (20)$$

which makes it possible to compute the relative error made in the computation of R_w if no correction is made to the pseudo-static SP taken from the SP log. The value of α in relation (20) can be taken from the chart of Fig. 7.

It is interesting to study how, for a given shaly sand, the relative error on R_w is influenced by the resistivity of the mud, as represented by that of the mud filtrate R_{mf}. Fig. 14 shows three computed curves corresponding to the same shaly sand, containing 5 per cent of shale. For each curve, all conditions are maintained constant, except the resistivity of the mud: the different curves correspond to different values of the oil saturation. In particular, it is assumed that for a given curve the distribution of the fluids in the sand beds is the same for all values of R_{mf}. It is interesting to see that the error is small provided that the resistivity of the mud is not too different from that of the connate water. However, when the resistivity of the mud is substantially larger than that of the connate water, and particularly when there is a large oil saturation, the error, as computed, becomes very large. Were it not for the fact that a sharp SP log is necessary for the detection of the permeable beds and for correlation purposes, there would be a definite advantage in using muds having a resistivity as near as possible to that of the connate water. It seems at least interesting to compromise by using muds that are resistive enough to give a decent SP log — for example, about five times as resistive as the average connate water — but not excessively resistive, lest the computation of connate water salinity from the SP become too erroneous.

Effect of the Use of Two Successive Muds of Different Salinities on the Pseudo-Static SP of a Shaly Sand

In the case of a clean sand, the static SP depends almost entirely on the ratio between the resistivity of the last mud used and the resistivity of the connate water. It can be demonstrated that this is also the case for a shaly sand if it is one hundred per cent water-bearing, because, in that case, the resistivity of the sand varies proportionally with the resistivity of its impregnating water.

In the case of an oil-bearing shaly sand that has been penetrated successfully by two different muds, the resistivity of the sand streaks varies through the invaded zone, not only because the salinity of the water varies continuously, but also because the oil saturation increases progressively toward the uncontaminated zone.

A computation using the relation given earlier in this paper shows that the pseudo-static SP in such an oil-bearing shaly sand depends not only on the resistivities of the last mud and of the connate water, but also on the resistivity of the water in the intermediate zone. This result is illustrated by the numerical application of Fig. 15, which represents the variations of the pseudo-static SP of a shaly sand as a function of the resistivity half-way between the limits of the invaded zone, all other conditions remaining the same. The figure shows also the pseudo-static SP that would have existed for that same shaly sand, if it had been entirely water-bearing, and if it had the same salinity of connate water: in this case, the pseudo-static SP is independent of the variations of salinity through the invaded zone, provided that they are continuous.

It is interesting to note that, according to the above theory, the use of a first mud, more conductive than the connate water, improves the pseudo-static SP of an oil-bearing shaly sand as finally measured with a fresh mud, and brings it nearer to the static SP of a clean sand.

Shaly Sand in Which the Clay Material is Disseminated in the Sand

The clay material is frequently disseminated in the sand, as a coating around the sand grains. In that case, the thin network of clay is everywhere side by side with the network

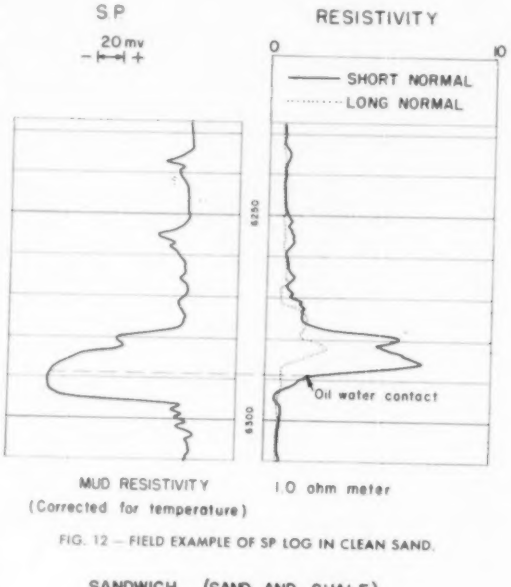


FIG. 12 — FIELD EXAMPLE OF SP LOG IN CLEAN SAND.

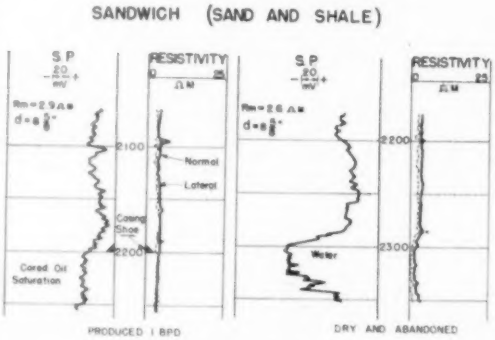


FIG. 13 — A PENNSYLVANIAN SAND IN HEWITT AREA, SOUTHERN OKLAHOMA.

of capillary water. This case is equivalent to that of alternate thin layers of sand and shale, except that the alternate layers have become of microscopic thickness. The conclusions arrived at for alternate thin layers remain valid, but should be considered only in a qualitative way.

The case where clay is present in the sand, in the form of clay grains isolated from each other, can also be considered. Such an occurrence may result from the transformation of feldspar grains that were originally deposited with the sand. In that type of shaly sand, the clay grains that are surrounded by a homogeneous electrolyte, as is the case in the uncontaminated zone, for example, are electrically in equilibrium, and therefore inert. On the contrary, the clay grains which are in the diffusion zone, where the salinity varies continuously with the radial distance from the hole, form with the heterogeneous electrolyte that surrounds them as many small cells, each of which produces only a very small amount of current. All these small currents flow from the clay grains into the electrolyte on the side where the salinity is minimum, flow around the clay grains, and back into them from the side where the salinity is maximum. Since the salinity gradient is always radial, with respect to the hole, and in the same direction, all the small potential drops produced in the ground by the small SP currents around the clay grains add their effect to build up a potential difference across the invaded zone.

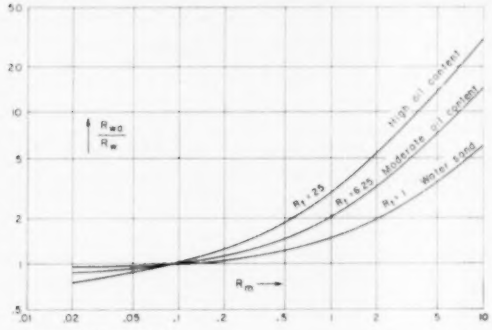


FIG. 14 — RELATIVE VALUE $\frac{R_{wa}}{R_w}$ OF THE APPARENT CONNATE-WATER RESISTIVITY IF COMPUTED FROM THE DATA OF THE SP CURVE OPPOSITE A SHALY SAND, AS A FUNCTION OF THE MUD RESISTIVITIES.

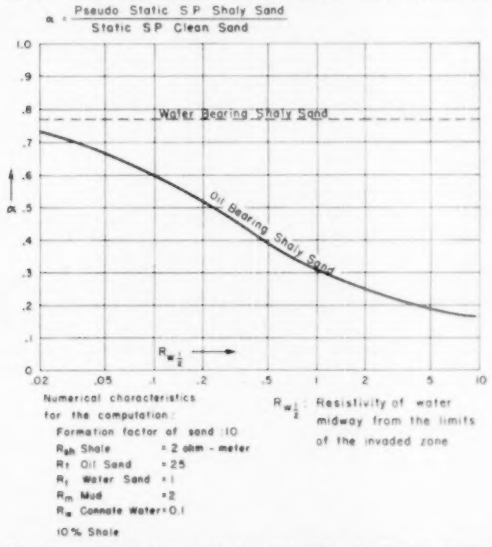


FIG. 15 — PSEUDO-STATIC SP OF A SHALY SAND PENETRATED BY TWO SUCCESSIVE MUDS OF DIFFERENT RESISTIVITIES.

If both the resistivity of the shaly sand, and that of its impregnating water, vary throughout the invaded zone according to an exponential law with respect to the radial distance, the SP reduction coefficient for the case of disseminated clay grains, can be expressed approximately by:

$$\alpha = 1 - 3p \frac{\log \frac{2R_{sh} + R_i}{2R_{sh} + R_i}}{\log \frac{R_i}{R_i}} \quad \ldots\ldots\ldots \quad (21)$$

with as usual:

$$\alpha = \frac{\text{pseudo-static SP of shaly sand}}{\text{static SP of clean sand}}$$

This expression has been established by a mathematical reasoning which involves a certain measure of approximation. It should be considered only as rough approach to the value of α when the percentage p of clay by volume is small (less than 5 per cent), and it becomes otherwise quite erroneous.

In the general case where shales are present in the sand bed, both as continuous layers and as disseminated grains, an approximate value for α can be roughly determined from the charts of Fig. 7 and 8, by taking p equal to the total percentage of shale, either stratified or granular.

Effect of the Electrofiltration EMF's

The electrofiltration emf's are due to the differential pressure between the mud column and the sand beds: they are located across the mud cake, as represented in Fig. 16.

If the mud cake is very thin, and if the thicknesses of the individual beds of sand and shale are small in comparison with the radius of the hole, the contribution of the electrofiltration phenomenon to the pseudo-static SP can be established in a way very similar to that used for the case of the electrochemical emf's. In this case, the potential drop, PD_f, which measures the pseudo-static SP due to electrofiltration, occurs partly in the mud and partly in the shale beds, and it is given approximately by the formula:

$$PD_f = E_f \frac{1}{1 + \frac{p}{1-p} \frac{R_m + R_i}{R_m + R_{sh}}} \quad \ldots\ldots\ldots \quad (22)$$

where:

E_f = electrofiltration emf,
p = proportion of interbedded shale,
R_m = resistivity of the mud,
R_i = resistivity of the invaded zone in the sand streaks immediately behind the mud cake,
R_{sh} = resistivity of the shale.

The expressions (4), (9) and (14), given in the earlier part of this paper, are valid only when the depth of invasion of mud filtrate is very great, at least in comparison with the individual thickness of each bed. In the case of moderate invasion, the pseudo-static SP would have a value intermediate between those derived from these equations and equation 22.

It is interesting to notice that, in the ideal case where no invasion is present, the pseudo-static SP involving both electrochemical and electrofiltration emf's, would be given by the same expression, where E_s would be replaced by the total electromotive force.

Variation of the K Coefficient of Shale Samples When Measured with Solutions of High Salinities

The behavior of certain shales, which do not show the same K coefficient when placed between concentrated solutions of sodium chloride as when placed between dilute solutions, might be explained by considering these shales as being in fact shaly sands with a very large proportion of shale, and only a few very thin permeable streaks. This is illustrated schematically in Fig. 17 which represents such a type of shale placed in a sodium chloride chain.

Using the usual notations a, b and c for the emf's at the different boundaries, and designating by PD_{sh} the potential drop produced horizontally in the core by the internal SP current due to the salinity change along the thin permeable streaks, one obtains for the apparent total emf E_s measured between the two extreme solutions:

$$E_s = a - b - PD_{sh} + c = (a + b + c) - PD_{sh}$$

When the salinities S_1 and S_2 are low, the resistivity of the permeable streaks, as impregnated by either of the two solutions, or their mixture, is high. Since, in addition, the permeable streaks are much thinner than the adjoining shale streaks, the conditions are those of a shaly sand for which the conductance ratio:

$$q = \frac{p}{1 - p}\frac{R_t}{R_{sh}}$$

is very high. In that case, and according to relation (15) or the chart of Fig. 7, PD_{sh} is very small, and, therefore, E_s is equal to E and satisfies the formula:

$$E = K \log \frac{S_1}{S_2}$$

When, however, the salinities S_1 and S_2 are high, the resistivity of the permeable streaks becomes low and the conductance ratio q falls down to a level where PD_{sh} is no longer negligible. The apparent emf E_s, as measured, should, therefore, be less than that indicated by the above relation.

There might be other reasons, for example of electro-chemical nature, for the abnormal value of the emf given by certain shales with concentrated solutions, and the above reasoning should be considered only as a suggestion toward a reasonable and simple explanation which needs to be checked by laboratory measurements.

CONCLUSION

The problem of shaly sands has been approached from a purely theoretical point of view in order to analyze the respective influence of the different parameters involved on the value of the pseudo-static SP of these shaly sands, as compared to the static SP of clean sands under similar conditions.

The conditions asumed may well have been oversimplified, but the theory, as it is, seems sufficient to explain most of the facts that have been observed in practice. This does not mean that other phenomena are not involved, and a careful check of data from electric logs and core analyses in favorable cases will determine to what extent the computed formulae can be considered better than a qualitative approximation. Two of the essential conclusions should remain, at least qualitatively. One is that the pseudo-static SP of a shaly sand is not only a function of the shale content but is also influenced, to a very large extent, by the relative resistivities of the sand and shale, so that the corresponding SP deflection decreases in a large measure when oil saturation increases. The other is that, if the salinity of the connate water is to be computed from the amplitude of the SP, it is essential not to use muds that are a great deal more resistive than the connate water.

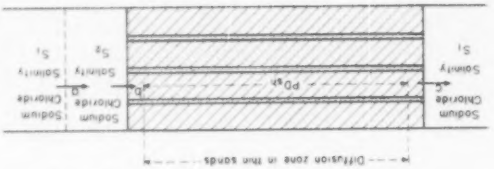


FIG. 16 — EFFECT OF THE ELECTROFILTRATION EMF.

FIG. 17 — SODIUM CHLORIDE CHAIN CONTAINING SHALE BRIDGE WITH VERY THIN LONGITUDINAL SAND STREAKS.

The charts and formulae established by computations, which are shown in this paper, obviously could be used to determine certain parameters involved if the other parameters are known. It seems reasonable, therefore, to assume that the above analysis could lend itself to quantitative approximations of certain characteristics of shaly sands. Such an application seems, however, premature, at least until field experiments have determined the practical value of the theoretical deductions.

In any case, it is hoped that the discussion will prove useful as a help toward a better understanding of the SP phenomena in the case of shaly sand, and that it will encourage further studies of the problem.

ACKNOWLEDGMENT

The author wishes to acknowledge the efficient cooperation of M. Martin and A. Poupon in the preparation of the final draft and in the computation of the theoretical examples given in the paper. He also wishes to express his appreciation to the oil companies for their courtesy in making examples available.

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Oil And Gas Developments In North Central Texas During 1949

By J. B. HARRELL, JR.,* Member AIME

The counties included in North Central Texas correspond to those in District 7-B of the Railroad Commission. Prior to this year, Wise County has been included with this group; effective this year, however, Wise County is included in the North Texas District, leaving the following counties in North Central Texas: Brown, Callahan, Coleman, Comanche, Coryell, Eastland, Erath, Fisher, Hamilton, Haskell, Hood, Jones, Lampasas, Mills, Nolan, Palo Pinto, Parker, San Saba, Shackelford, Stephens, Stonewall, Somervell, Taylor and Throckmorton.

Statistics are presented in this report by fields as designated by the Railroad Commission. In certain cases, due to insufficient data, several fields have been grouped together under the general classification, "Other Fields."

The most productive county in this district to the end of 1949 has been Stephens County with a cumulative production of 143,416,767 bbl. Of this total, 3,114,450 bbl were produced during 1949 from 767 wells. The most productive county during the period covered by this report was Jones, which produced 5,253,715 bbl of oil from 1,183 wells, 197 of which were completed during 1949.

A total of 2,288 wells were drilled in this district during 1949. This represents an increase of 65.47 per cent over 1948. Of this total, 970 were completed as oil wells, 524 were gas wells, and 794 were dry holes.

One of the most important discoveries during 1949 was that of the Pardue Field in Fisher County. This field produced a total of 133,424 bbl of oil from 12 wells during 1949.

The Humphrey Gray Field in Jones County was another important discovery. A total of 16 wells had been completed to the end of 1949, from which 132,180 bbl of oil had been produced.

Other important discoveries during the year 1949 were as follows:

Callahan County

1. Star Oil Co., No. 1 Mrs. C. Smith..Cross Plains Sand.
2. B. F. Phillips No. 2 R. D. Williams. Morris Sand.

Coleman County

1. J. R. Penn & W. J. Fulwiller, Jr., No. 1 Kuykendall. Morris Sand.
2. Woods Drilling Co. No. 1 J. P. Mc Cord. Fry Sand.
3. Guy Mabee Drilling Co. No. 1 Chas. Kennedy. Palo Pinto Reef.
4. W. E. Stepp & L. J. Maxwell et al, Mrs. George Sparkman et al, No. 1. Breneke Sand.
5. Dunham & Young Oil Co. No. 1 Calvin Campbell. Marble Falls.
6. Anzac Oil Corp. et al, No. 3 Cora M. Burk. Marble Falls.
7. Haynes B. Ownby Drilling Co. et al, No. 2 E. O. Herring. Fry Sand.

Comanche County

1. Sohio Petroleum Co. No. 1 J. W. Ward. Mississippian.

Eastland County

1. Lone Star Producing Co. No. 1-C C. J. Kleiner. Mississippian.

Erath County

1. Amburgey Bros., Mc Clung, Wilkinson & Mc Clung No. 1. Ellenberger.

Fisher County

1. Skelly Oil Co., No. 11-A. Huddleston. Flippen.
2. Woods Drilling Co. No. 1 Bradford-Shell. Canyon Sand.
3. Lion Oil Co. No. 1 L. V. Horton, Cook Sand.
4. A. G. Hill & Walter Duncan No. 1 W. P. Bomar. Cook Lime.
5. Round Top Oil Co. No. 7-H E. A. Hall Fee. Canyon Sand.
6. Texas Pacific Coal & Oil Co. No. 1 S. P. Tucker. Canyon Sand.

Haskell County

1. Pan American Production Co. No. 1 W. G. Wendeborn. Strawn.
2. Danciger Oil & Refining Co. No. 1 C. L. Bogard. Strawn.
3. Humble Oil & Refining Co. No. 1 C. G. Burson, Jr. Strawn.
4. Stanolind Oil & Gas Co. No. 1 John M. Pace. Canyon Reef.

Jones County

1. S. C. Herring No. 1 Effie Anderson. Flippen.
2. J. W. Gehle No. 1 J. A. White. Flippen.
3. Roark & Hooker & West Central Drilling Co. No. 1 Alec Carter. Hope Lime.

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*General Superintendent for M. E. Daniel.

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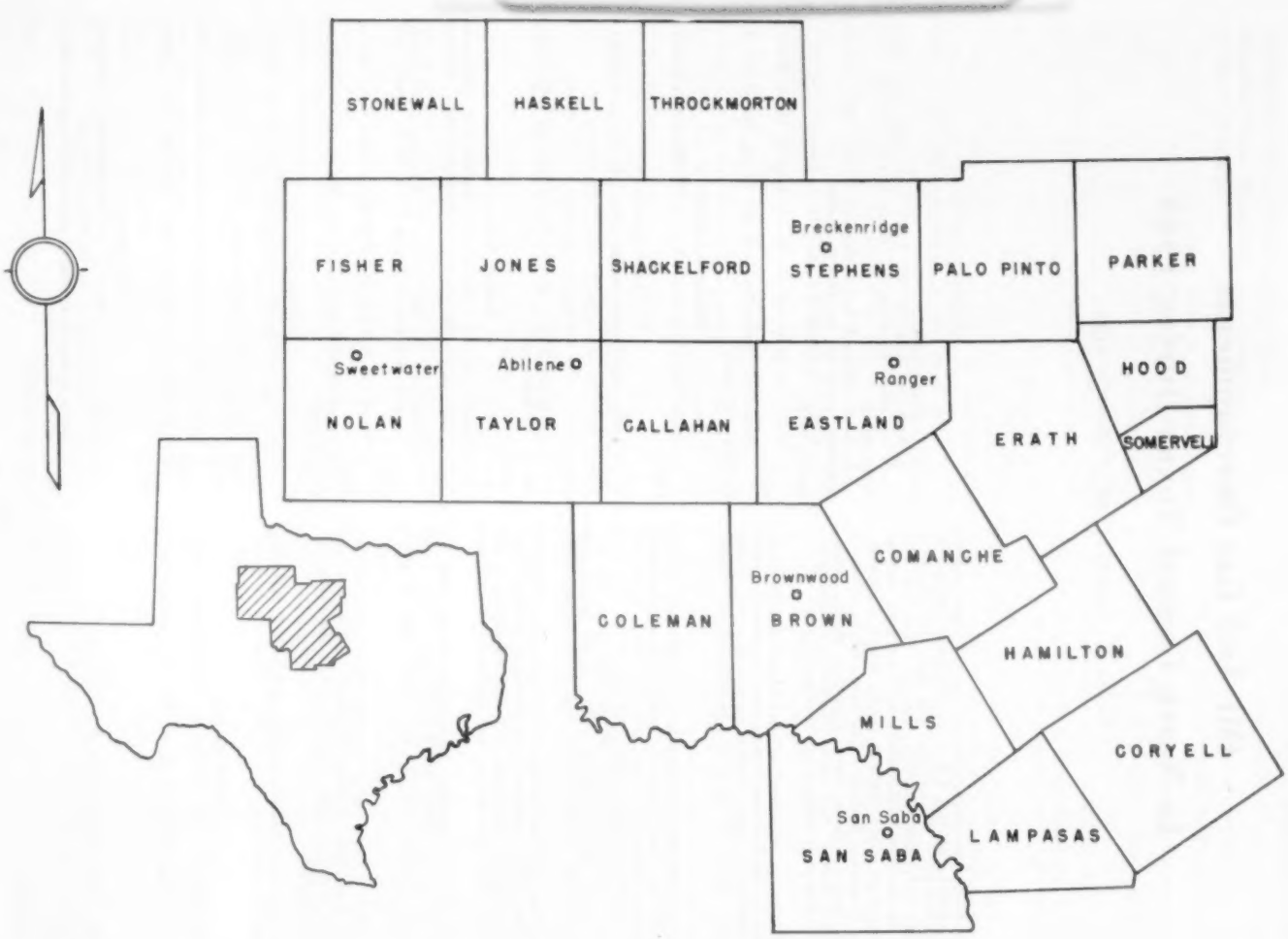

NORTH CENTRAL TEXAS

4. Ungren & Frazier No. 1 W. E. Hatchett. Flippen.
5. Roark, Hooker & Roark Drillers, Inc. No. 1 John R. Collins. Strawn.
6. C. U. Bay & Taubert Drilling Co. No. 2 E. E. Farnsworth. Gunsight.
7. Manley Bros. & Barron No. 2 Abbie Harvey. Upper Hope Sand.
8. Walter Duncan & A. G. Hill No. 1 Mrs. Bettie Burleson. Canyon Sand..
9. Moutray, Moore Drilling Co. No. 1 Luther Weeks. Unidentified Sand.

Nolan County

1. Iowa-Payne Oil Co. No. 1 N. L. Mc Leod. Strawn.
2. Skelly Oil Co. No. 1 E. A. Ater. Ellenberger.

Palo Pinto County

1. Ernest Loyd No. 6-A V. La Neve. Unidentified Sand.

Shackelford County

1. G. E. Kadane & Sons et al, No. 2 Sanders. Caddo.
2. Big West Drilling Co. No. 1 J. H. Nail. Cook Sand.
3. G. E. Kadane & Sons & Harry Beaumont No. 1 C. C. De Lafosse. Strawn.
4. Danciger Oil & Refining Co. & Intex Oil Co. No. 1 Edwards Heirs. Conglomerate.
5. Roeser & Pendelton, Inc. No. 1 E. C. Evans. Ellenberger.
6. Oxford Drilling Co. No. 1-A Mc Mahon & Doss. Ellenberger.
7. M. J. Mitchell No. 1 M. J. Mitchell, J. S. Scott et al. Ellenberger.
8. Humble Oil & Refining Co. No. 1-B F. G. Coates Trustee, Cisco Series Sand.
9. M. J. Mitchell No. 2 Scott et al. Lake Sand.
10. Great Expectations Oil Corp. & J. L. Douglas No. 1-B Chloe A. Nail. Cisco Series Sand.
11. H R H Drilling Co. No. 1-B Dell Newell. Tannehill Sand.
12. Jack H. Moore No. 2 Dawson & Conway. Saddle Creek.
13. P. S. Kendrick & M. C. Alsoton No. 3 T. W. Lee. Lower Hope.

Stephens County

1. Bond Oil Co. et al, No. 1 Ross Sloan et al. Mississippian.
2. Star Oil Co. Inc. No. 1-E Ed Ford. Caddo.
3. Mc Elroy Ranch Co. No. B-1 B. G. O'Neal. Caddo.
4. Mc Elroy Ranch Co. No. 1 Baker et al. Ellenberger.
5. Mc Elroy Ranch Co. No. 1 B. G. O'Neal. Caddo.
6. Connally-Thornton et al, No. 1 H. W. Harte. Strawn.
7. Texas Pacific Coal & Oil Co. No. 12 A. A. Atkins Account 1. Mississippian.
8. Mc Elroy Ranch Co. No. 1 W. H. Green. Mississippian.
9. Mc Elroy Ranch Co. No. 2 Barker et al. Caddo.
10. Mc Elroy Ranch Co. No. 1 R. W. Tipton. Mississippian.
11. Mc Elroy Ranch Co. No. 1 Ackers. Caddo.
12. Texas Pacific Coal & Oil Co. No. 1 S. L. Harris. Marble Falls.

Taylor County

1. West Central Drilling Co. No. 1-A Jack K. Hogan. Ingram.
2. Twin Oil Corp- et al, No. 1-B City of Abilene. Saddle Creek.
3. Crown Central Petroleum Corp. No. 1 W. T. Curb. Dothan Lime.
4. Geochemical Surveys et al, No. 1-A T. J. Bird. Frazier.
5 Geochemical Surveys et al, No. 1 Craig Humphreys. Cook.
6. Geochemical Surveys et al, No. 2 Craig Humphreys. Ingram.
7. J. P. Production Co. et al, No. 1 N. V. Atwood. Gardner Sand.
8. Geochemical Surveys No. 1 J. S. Pinckley. Ingram.
9. Hiawatha Oil & Gas Co. No. 1 R. E. Carter. Jennings Sand.

Throckmorton County

1. Humble Oil & Refining Co. No. 3 Kirk Ledbetter. Conglomerate.
2. James H. Snowden No. 1 Eleanor Gentry. Mississippian.
3. Fred M. Manning, Inc. No. 1 Goodstein-Brown Unit L. Caddo.
4. A. Kriss & H. Schwartz No. 2 M. Daws. Canyon Sand.
5. Woodley Petroleum Co. No. 1 Garland H. Webb. Mississippian.
6. Woodley Petroleum Co. No. 1 Henry S. Bryson. Mississippian.
7. James H. Snowden et al, No. 1 Norton. Mississippian.
8. Fred M. Manning Inc. No. 1 A. E. Nash. Marble Falls Conglomerate.
9. James H. Snowden et al, No. 1 G. D. Dickie Unit 1. Mississippian.
10. Woodley Petroleum Co. No. 2 Charles F. Leathers. Mississippian.
11. Deep Rock Oil Corp. No. 1 Thomas W. Forman. Caddo.
12. Turner & Duvall No. 1 E. A. Possern. Mississippian.
13. The Mudge Oil Co., No. 1 Ross Sloan B. Mississippian.
14. Kingery & Patterson No. 1 Mrs. D. S. Mc Donald. Strawn.
15. Rock Hill Oil Co. No. 1 Tom Morrison. Strawn.
16. Dwight M. Ross No. 1 Sam R. Davis. Mississippian.
17. Warren Oil Corp. No. 1 Malcom. Mississippian.

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The writer also wishes to thank M. E. Daniel for permission to prepare this report.

TABLE I - OIL AND GAS PRODUCTION STATISTICS FOR NORTH CENTRAL TEXAS IN 1949

LINE NUMBER	FIELD (County)[a]	PRODUCING FORMATION NAME AND AGE[b]	YEAR OF DISCOVERY	OIL PRODUCTION			GAS PRODUCTION			GAS/OIL RATIO[c] MCF/BBL	CONDENSATE PRODUCTION Thousands of Bbl	
				AREA PROVED ACRES	BARRELS TO END OF 1949	BARRELS DURING 1949	AREA PROVED ACRES	MILLION CU FT[c] TO END OF 1949	MILLION CU FT[c] DURING 1949		TO END OF 1949	DURING 1949
	Brown											
1	Blake Caddo	Caddo, Pen	1948	960	163,412	64,872						
2	Other Fields [1]	Pen, Mis, Ord	1917	10,540	33,591,002	254,976						
3	Total Brown County			11,500	33,754,414	319,848						
	Callahan											
4	Baxin	Ellenberger, Ord	1947	960	102,968	45,752						
5	Caddo Peak	Ellenberger, Ord	1948	80	4,521	621						
6	Jessie	Cisco Series Sand, Pen	1948	20	1,260	735						
7	Millthorn	Moutray Sand, Per	1948	80	20,654	14,964						
8	Mikapam	Morris Sand, Pen	1949	40	1,545	1,545						
9	Morrisett	Cook Sand, Pen	1948	80	32,620	25,425						
10	Qulin	Ellenberger, Ord	1948	40	396	157						
11	Scranton	Cathey, Pen	1949	160	155,586	6,328						
12	Other Fields [2]	Per to Ord	1930	7,760	16,607,668	236,190						
13	Total Callahan County			9,220	16,927,218	331,717						
	Coleman											
14	Anzac Morris	Morris-Cross Cut, Pen	1937	280	533,768	54,979						
15	Bead Mountain	Strawn, Pen	1947	140	71,233	14,622						
16	Burroughs	Capps, Pen	1946	20	8,523	436						
17	Campbell, Henry	Canyon Sand, Pen	1948	20	6,950	4,691						
18	Coker	Morris, Pen	1942	1,140	1,057,218	62,641						
19	Dunham and Young	Marble Falls, Pen	1949	80	4,575	4,575						
20	Gayle	Morris, Marble Falls	1926	360	639,441	8,241						
21	Goldsboro	Gardner & Gray, Pen	1927	380	1,410,669	39,134						
22	Jim Ned	Morris & Gray, Pen	1941	130	76,418	4,482						
23	Moore	Canyon, Pen	1946	60	18,684	3,804						
24	Novice [3]	Gray & Gardner, Pen	1927	1,600	1,935,171	104,966						
25	Oaden-Mabee	Palo Pinto Reef, Pen	1949	300	32,536	32,536						
26	Overall	Cisco & Strawn, Pen	1928	280	1,606,836	19,272						
27	Rhodes, Jack A.	Morris Sand, Pen	1949	80	10,347	10,347						
28	Silver Valley	Gray, Pen	1941	640	998,911	102,945						
29	Templeton	Gray, Pen	1946	480	344,497	108,406						
30	Williams	Gardner & Gray, Pen	1944	840	1,111,287	160,591						
31	Other Fields [4]	Per, Pen, Ord	1910	6,920	9,787,773	331,647						
32	Total Coleman County			13,750	19,654,837	1,068,315						
	Comanche											
33	Amity	Blake, Pen	1939	650	533,645	23,852						
34	Kirk	Marble Falls	1948	4,640	436,592	150,575						
35	Smith-Morgan	Blake, Pen	1941	80	46,744	3,074						
36	Other Fields [5]	Pen & Ord	1919	8,970	1,706,601	25,287						
37	Total Comanche County			14,340	2,783,582	202,788						
	Eastland											
38	Carbon	Caddo, Pen	1939	250	100,038	681						
39	Kleiner Mississippian	Mississippian Reef	1948	680	280,800	204,748						
40	Other Fields [6]	Pen, Mis, Ord	1917	22,000	104,837,332	793,242						
41	Total Eastland County			22,930	105,218,170	998,671						
	Erath											
42	Aron	Marble Falls, Pen	1948	80	1,707	673						
43	Other Fields [7]	Pen & Ord	1920	2,080	40,132	21,192						
44	Total Erath County			2,160	41,839	21,865						
	Fisher											
45	Bennett	Camp Colorado, Pen	1938	120	94,860	2,996						
46	Bonar	Cook Lime, Pen	1949	30	5,518	5,518						
47	Dakota	Camp Colorado, Pen	1946	700	786,995	258,410						
48	Mc Cauley [8]	Canyon Pen Camp Colorado, Pen Hope, Pen	1941	350	308,377	17,488						
49	Pardue	Swastika, Ord, Pen	1949	360	133,424	133,424						
50	Roby	Flippen, Pen	1948	200	69,639	67,101						
51	Rotan	Camp Colorado, Pen	1936	500	2,004,632	27,168						
52	Round Top	Hope & Canyon, Pen Swastika Canyon, Pen	1947	3,840	1,566,091	1,087,470						
53	Royston	Royston, Pen	1928	3,250	13,351,788	148,323						
54	Sands Hill	Canyon, Pen	1949	80	24,478	24,478						
55	Total Fisher County			9,190	18,345,802	1,772,376						
	Haskell											
56	Humphrey Chapman	Canyon, Pen	1946	720	312,527	68,122						
57	South Haskell	Canyon, Pen	1949	00	35,626	35,626						
58	Jud	Strawn, Pen	1949	180	102,764	102,764						
59	Lasson	Canyon, Pen	1941	370	489,197	102,244						
60	Sagerton, South	Strawn, Pen	1949	60	4,223	4,223						
61	Weinert	Strawn, Pen	1949	120	35,748	35,746						
62	Other Fields [9]	Hope & Canyon, Pen	1928	1,140	338,233	42,926						
63	Total Haskell County			2,680	1,318,318	391,653						

LINE NUMBER	NUMBER OF WELLS[C]			WELLS PRODUCING[F] DEC. 1949			RESERVOIR PRESSURE LB PER SQ INCH		SECONDARY RECOVERY[H]	CHARACTER OF OIL[A]		PRODUCING FORMATION					DEEPEST TOTAL TESTED[B] TO END OF 1949	
	COMPLETED TO END 1949	1949 COMPLETED	1949 ABANDONED	OIL FLOWING	OIL ARTIFICIAL LIFT	GAS	INITIAL	AVG.-END 1949		GRAVITY A.P.I.	SULPHUR PER CENT	CHARACTER[I]	POROSITY PER CENT[J]	DEPTH TO TOP OF PRODUCING ZONE FT[K]	PROD. THICKNESS AVG. FT NET	STRUCTURE[E]	NAME	DEPTH OF HOLE FT
1	24	1		4	20					44		L	P	2,040	20	A	Ell, Ord	3,857
2	2,433	26	60	1	570					27-44		S L		3,000		A N A L	Pre-Cam	4,149
3	2,457	27	60	5	590													
4	12	8	2	1	7					45		D	P F	3,820	15	A	Ell, Ord	
5	1		1							39		D	P F	3,970	3	A	Ell, Ord	3,973
6	1		1							20		S	P	554	8	A	Ell, Ord	4,667
7	4	1		1	2					38		S	P	1,319	5	A		
8	2	2		2						41		S	P	2,140	13			
9	4	1			4					40		S	P	1,696	20	A		
10	1		1									D	P F	4,423	3	A	Ell, Ord	4,425
11	9				8					39		S	P	1,675		N	Ell, Ord	4,140
12	1,316	39	68	50	884					43		S L	P	4,300		A	Ell, Ord	4,942
13	1,350	51	73	54	905													
14	21	3	2	11	4					41		S	P	2,760		N	Stra, Pen	2,695
15	4	1			3					46		S	P	2,796	7	A	Ell, Ord	3,845
16	1				1					43		S	P	3,142		N	Ell, Ord	4,150
17	1				1					32		S	P	1,424		A		
18	31	1	1	13	11					43		S	P	2,630- 3,460		N	Stra, Pen	3,660
19	3	3		3						30		L	P	2,311		N	Marble Falls, Pen	2,355
20	31			5						41		S C	P	1,900- 3,200		N	Marble Falls, Pen	3,220
21	15			5	7					40		S	P	3,800- 3,975		T	Ell, Ord	4,702
22	8			1	2					43		S	P	3,400- 3,900		T	Marble Falls, Pen	4,230
23	3				3					30		S	P	1,464		N		
24	61	3		54	1					42		S	P	3,533- 3,600		T	Ell, Ord	4,526
25	15	15		5	10					44		L	P	3,071		A		3,114
26	51	1	3	1	5					40		S	P	2,150		D	Ell, Ord	
27	2	2		2						43		S	P	2,655		N		
28	30			20	1					43		S	18	2,800- 3,600		N	Marble Falls, Pen	4,169
29	13	2		12						43		S	P	3,457	20	A		
30	29		1	17	3					45		S	15-24	3,700- 3,900	15	N	Marble Falls, Pen	4,151
31	766	54	68	26	359					44		S L	P	3,850		A N	Ell	4,704
32	1,085	85	75	175	411													
33	65				65					38		S	P	750		N	Marble Falls, Pen	3,080
34	116	16	20	42	10					40		L	P	2,800		A		
35	9				8					38		S	P	725		N	Ell, Ord	3,300
36	299	27	6	5	45					38		S L	P	4,000		N	Pre-Cam	5,260
37	489	43	26	47	128													
38	14				1					40		L	P	2,500		N	Marble Falls, Pen	3,577
39	17	4	1	10	7					43		L	P	3,869		A	Ell, Ord	4,042
40	3,321	25	25	40	345					33-43		S L	P	1,200- 4,200		A N	Pre-Cam	5,645
41	3,352	29	26	50	353													
42	2		2							42		L	P	2,935		A	Ell, Ord	3,240
43	94	2	6	1	12							L S	P	1,625- 3,400		N A	Can	7,165
44	96	2	8	1	12													
45	4	2	2		2					43		L	P	3,686		N	Cisco, Pen	3,902
46	1	1	2	1						42		L	P	3,556		A	Cook Lime	3,580
47	23	2	2	21	5					43		L	P	2,600- 4,374	75 ±	A		
48	11		2		4					42		L	P	3,000- 3,160		A N	Can, Pen	4,156
49	12	12	3	8	4					40-42		L S	P	3,772- 3,948	8 36	A	Ellen, Pen	5,984
50	6	5	2	1	4					38		L	P	3,523		A		
51	42				11					40		L	P	3,300- 5,350		A N	Bend, Pen	5,742
52	93	61	8	87	6					40		L S	P	3,900- 4,800		A	Can, Pen	4,939
53	118		10		47					37		L	P	3,100		A	Pre-Cam	6,494
54	1	1	2	1						38		S	P	4,723		A		
55	311	84	33	119	83													
56	18		2		17					43		L	P	4,082		A		5,470
57	3	3	5	3						37		L	P	3,610	15	A		3,624
58	6	6	4		6							S	P	5,023	5	N	Caddo	5,848
59	14	1	2	3	8					43		L	P	4,082		A	Ell, Ord	4,607
60	2	2	2		2					40		S	P	4,772	8	N		
61	4	4	1	2	2					38		S	P	4,735	20	N		
62	31	6	13		20					37		S L	P	1,500- 2,850		A N	Mix	5,994
63	78	22	29	8	55													

TABLE I - Continued OIL AND GAS PRODUCTION STATISTICS FOR NORTH CENTRAL TEXAS

LINE NUMBER	FIELD (County)[a]	PRODUCING FORMATION NAME AND AGE[b]	YEAR OF DISCOVERY	OIL PRODUCTION			GAS PRODUCTION			GAS/OIL RATIO[d] MCF/BBL	CONDENSATE PRODUCTION Thousands of Bbl	
				AREA PROVED ACRES	BARRELS TO END OF 1949	BARRELS DURING 1949	AREA PROVED ACRES	MILLION[c] CU FT TO END OF 1949	MILLION[c] CU FT DURING 1949		TO END OF 1949	DURING 1949
	Jones											
64	Akard	Flippen, Pen	1938	560	779,272	38,796						
65	Akens	Hope, Pen	1948	80	11,537	4,941						
66	Anderson	Flippen, Pen	1949	200	72,605	72,605						
67	Anson	Canyon, Pen	1948	680	139,081	127,697						
68	Anson, Flippen	Flippen, Pen	1948	40	2,019	1,727						
69	Anson, West	Strawn, Pen	1948	40	9,098	8,303						
70	Avoca	Canyon, Pen	1937	1,080	5,621,106	321,157						
71	Avoca, North	Canyon, Pen	1940	300	700,125	52,501						
72	Avoca, West	Canyon, Pen	1941	100	114,704	8,265						
73	Bartlett	Swastika, King, Pen	1947	2,490	1,113,231	747,260						
74	'B B'	Swastika, Pen	1948	40	40,980	40,980						
75	Farnsworth	Gunsight, Pen	1949	90	6,176	6,176						
76	Fragosa	Gunsight, Pen	1948	240	117,345	93,204						
77	Griffin	Canyon, Pen	1938	1,000	5,453,524	314,037						
78	Hardy	Canyon, Pen	1943	860	1,008,509	350,180						
79	Hart	Wolfcamp, Per	1946	90	26,712	5,473						
80	Hatchett	Flippen, Pen	1949	60	12,220	12,220						
81	Hawley	Wolfcamp, Per, Cisco, Pen	1933	420	3,764,544	54,255						
82	Humphrey - Gray	Tannehill Sand	1949	320	132,180	132,180						
83	Largent	Strawn, Pen	1948	200	43,642	38,494						
84	Lewis Steffens	Bluff Creek, Pen	1936	1,900	3,341,011	113,527						
85	Minter	Cisco, Pen	1946	60	37,358	8,694						
86	Nenda	Flippen, Pen	1945	60	47,422	4,146						
87	Noodle Central	Hope & Swastika, Pen	1943	400	957,459	108,913						
88	Noodle South	Camp Colorado, Pen, Swastika, Pen	1941	660	817,955	71,452						
89	Pitzer	Strawn, Pen	1946	720	499,601	286,102						
90	Ramsey	Saddle Creek, Pen	1948	100	33,016	27,740						
91	Reid	Cisco, Pen	1940	145	52,612	2,039						
92	Sayles	Flippen, Pen	1932	1,350	3,903,247	169,226						
93	Stanley	Strawn, Pen	1949	120	7,459	7,459						
94	Stith	Flippen, Hope, Pen	1940	150	237,122	15,011						
95	Strand	Palo Pinto, Pen	1941	460	451,933	46,547						
96	Triplett	Flippen, Pen	1940	85	97,277	1,769						
97	Winberly	Swastika, Gunsight, Pen	1941	3,340	8,162,280	993,103						
98	Other Fields [10]	Per & Pen	1926	7,450	14,494,693	967,536						
99	Total Jones County			25,840	52,309,055	5,253,715						
	Nolan											
100	Mc Leod	Strawn Sand, Pen	1949	40	2,608	2,608						
101	Roscoe	Ellenberger, Ord	1949	40	5,172	5,172						
102	Nolan County Regular		1939	40	10,302	4,569						
103	Total Nolan County			120	18,082	12,349						
	Palo Pinto											
104	Cantey	Ellenberger, Ord	1948	160	1,961	370						
105	Gordon	Marble Falls, Pen	1932	120	29,137	6,955						
106	Other Fields [11]	Strawn, Marble Falls, Pen	1915	7,020	5,751,832	92,862						
107	Total Palo Pinto County			7,300	5,782,930	100,187						
	Parker											
108	Buzz	Ellenberger, Ord	1949	20	2,168	2,168						
109	Total Parker County			20	2,168	2,168						
	Shackelford											
110	Hubbard Creek	Ellenberger, Ord	1946	640	240,703	104,212						
111	Ivy	Cook, King, Palo Pinto, Pen	1937	1,550	4,034,759	159,940						
112	Kadane-Beaumont-Strawn	Strawn, Pen	1949	300	27,931	27,931						
113	Nail	Bluff Creek, Cook, Pen	1927	460	1,027,927	25,343						
114	P & R	Ellenberger, Ord	1948	160	31,636	28,521						
115	Shark Nail	Cisco, Pen	1942	100	121,568	10,940						
116	Other Fields [12]	Per, Pen, Ord	1911	17,330	51,151,000	1,946,413						
117	Total Shackelford County			20,540	56,605,544	2,303,300						
	Stephens											
118	Breamsville	Chappel, Mis	1943	280	351,424	31,848						
119	Chaney	Caddo, Pen	1947	300	203,169	63,695						
120	Crystal Falls	Caddo, Pen, Chappel, Mis	1948	200	131,376	118,120						
121	Double 'H' Ellen	Ellenberger, Ord	1948	920	283,069	229,102						
122	Finches	Caddo, Pen	1948	80	29,671	25,486						
123	Hill	Chappel, Mis	1943	240	295,774	16,529						
124	Hill Marble Falls	Marble Falls, Pen	1946	40	76,353	15,642						
125	Loving	Caddo, Pen	1939	760	330,759	16,084						
126	Manning - O'Connor	Caddo, Pen	1946	1,200	843,199	289,840						
127	O'Neal Caddo	Caddo, Pen	1949	60	17,467	17,467						
128	O'Neal Ellenberger	Ellenberger, Ord	1949	60	8,980	8,980						

LINE NUMBER	NUMBER OF WELLS[c]			WELLS PRODUCING[f] DEC. 1949			RESERVOIR PRESSURE LB SQ PER INCH		SECONDARY RECOVERY[g]	CHARACTER OF OIL[h]		PRODUCING FORMATION					DEEPEST ZONE TESTED[m] TO END OF 1949	
	COMPLETED TO END 1949	1949		OIL		GAS	INITIAL	AVG./END 1949		GRAVITY A.P.I.	SULPHUR PER CENT	CHARACTER[l]	POROSITY PER CENT/	DEPTH TO TOP OF PRODUCING ZONE FT[k]	PROD. THICKNESS AVG. FT NET	STRUCTURE[m]	NAME	DEPTH OF HOLE, FT
		COMPLETED	ABANDONED	FLOWING	ARTIFICIAL LIFT													
64	34				26					39		S	P	2,150		A	Cisco, Pen	2,580
65	2				2					45		S	P	2,271	3	A	Hope, Pen	2,276
66	5	5			5					38		S	P	2,640	16	P		
67	14	11	3	11	4					42		S	P	3,585	23	A		
68	1				1					39		E	P	2,270	8	A	Flip, Pen	2,278
69	2				2					41		S	P	4,310	30	A		5,322
70	59	4	4	31	18					42		L	25 x P	3,200	40	A	Ell, Ord	5,250
71	11	1	1		8					42		L	P	3,200		A	Can, Pen	3,431
72	3		1		1					42		L	P	3,240	12	A	Can, Pen	3,252
73	80	39	12	67	16					42		S	P	3,280-3,308	13 30	A		
74	1	1	1	4	3					41		S	P	3,017		A		
75	3	3		3								L	P	3,132	6	A	Ell, Ord	3,158
76	8	2			8					40		L	P	2,910	26	A	Ell, Ord	5,452
77	68		4	14	33					42		L	25 x P	3,200		A	Can, Pen	3,360
78	25	3		11	14					39		S	P	3,690		N	Can, Pen	3,756
79	3				3					41		S	P	2,172	10	A		
80	2	2		1	1							S	P	2,088	2	A		
81	113	1	9		40					39		S L	P	1,900-2,300		A	Cisco, Pen	2,722
82	16	16	5	8	8					34		S	P	1,629	17	A		
83	5	4		3	1					44		S	P	4,640		A		
84	214	5	7		142					39		S	P	1,800-1,950		N	Cisco, Pen	2,310
85	3	1			2					37		S	P	3,450		N		
86	3				3					38		L	P	2,865		A		3,403
87	20	2		14	6					43		L S	20 x P	2,700-2,800	15 x	A	Can, Pen	3,465
88	18			1	13					44		L S	20 x P	2,400-3,000	15	A	Ell, Ord	5,574
89	23	9	3	17	5					44		S	P	4,539		A	Ell, Ord	5,321
90	5	3	5							40		S	P	1,698	3	A		
91	7				2					41		L	P	2,545		A	Can, Pen	3,952
92	112	5	6	14	84					38		S	P	1,750-2,000		T N	Cisco, Pen	2,548
93	3	3	1	3						44		S	P	4,586		A		
94	8				7					43		S L	P	2,300-2,600		A	Cisco, Pen	2,750
95	10			1	5					41		L	P	1,600-3,400		A	Can, Pen	3,686
96	5				1					38		S	P	2,185		A	Cisco, Pen	2,920
97	146	17	8	112	87					42		L S	P	2,100-2,600		A		
98	565	60	74	12	305					35-43		L S	P	1,600-4,000		A N	Ell, Ord	6,020
99	1,597	197	144	327	856													
100	1	1	3		1					42		S	P	5,124		A	Ell, Ord	5,735
101	1	1	2		1					44		L	P	7,097		A	Ell, Ord	7,155
102	2		1		1					43		D	P	6,140	5	A	Ell, Ord	6,193
103	4	2	10		3													
104	4	2	2		2					40		D	P F	4,293	2	A	Ell, Ord	4,295
105	7			3						38		S	P	3,100-3,568		A	Ell, Ord	4,605
106	553	8	13	6	35					38-48		S L	P	4,320		A N	Ell, Ord	5,123
107	564	10	15	9	37													
108	1	1	1							46		L	P	6,658		A	Ell, Ord	6,688
109	1	1	1															
110	18	10	1	6	11					42		L	P F	4,198		A	Ell, Ord	4,310
111	89	3	13		55					34-42		S L	P	1,700-3,200		A	Ell, Ord	5,222
112	10	10			10					41		S	P	2,057		A		
113	47				16					38		S	P	1,400-1,600		N	Stra, Pen	3,306
114	4	1		1	3					42		D	P F	4,523	5	A	Ell, Ord	4,538
115	7				6					38		S	P	1,500		N	Cisco, Pen	1,692
116	2,852	133	172	42	1,848					36-45		S L	P	4,600		A	Ell, Ord	5,316
117	3,027	157	186	49	1,949							S L				I N		
118	6			2	3					36		L	P	4,155		N	Ell, Ord	4,406
119	14	1	3	2	9					44		L	P	3,346		A		
120	5	3	1	4	1					40		L	P	3,416	34	A	Ell, Ord	4,675
										41				4,513	10			
121	26	20	6	10	13					43		D	P F	4,417	14	A	Ell, Ord	4,458
122	2	1			2					40		L	P	4,379	17	A	Ell, Ord	4,379
123	2			2						42		L	P	4,226		A	Ell, Ord	4,828
124	1			1						45		S	P	4,434		A	Ell, Ord	4,690
125	28	4	3	7	10					43		L	P	3,428	15	A	Ell, Ord	4,374
126	31	4	2	22	3					44		L	P	3,262		A		
127	2	2		1	1							L	P	3,249		A		
128	2	2		2						44		L	P	4,469		A	Ell, Ord	4,470

TABLE 1 - Continued OIL AND GAS PRODUCTION STATISTICS FOR NORTH CENTRAL TEXAS

LINE NUMBER	FIELD (County)[a]	PRODUCING FORMATION NAME AND AGE[b]	YEAR OF DISCOVERY	OIL PRODUCTION			GAS PRODUCTION			GAS/OIL RATIO[d] MCF/BBL	CONDENSATE PRODUCTION Thousands of Bbl	
				AREA PROVED ACRES	BARRELS TO END OF 1949	BARRELS DURING 1949	AREA PROVED ACRES	MILLION[c] CU FT TO END OF 1949	MILLION[c] CU FT DURING 1949		TO END OF 1949	DURING 1949
129	Ross Sloan	Mississippian, Mis	1949	90	4,650	4,650						
130	Stribling	Caddo, Pen	1939	360	246,194	5,710						
131	Other Fields [13]	Per, Pen, Mis, Ord	1915	51,460	140,604,682	2,351,297						
132	Total Stephens County			56,110	143,416,767	3,114,450						
	Stonewall											
133	Aspermont	Mississippian, Mis	1940	40	58,288	2,340						
134	Boyd	Canyon, Pen	1939	80	68,318	3,540						
135	Carlile	Canyon, Pen	1938	80	212,734	13,402						
136	Total Stonewall County			200	339,340	19,282						
	Taylor											
137	Bird	Dothan, Perm, Hope, Pen	1948	300	112,827	87,372						
138	Bowles	Cook, Pen	1937	120	126,219	1,431						
139	Caldwell Ranch	Saddle Creek, Pen	1949	280	35,504	35,504						
140	Ferrell	Cook, Pen	1947	150	34,273	28,883						
141	Gibson South, Gunsight Beef	Gunsight, Canyon Beef, Pen	1948	30	1,860	1,860						
142	Gibson	Dothan, Per, Flippen, Hope	1948	560	381,504	351,039						
143	Hogan	Hope, Pen	1949	60	1,561	1,561						
144	Ingram	Hope, Pen	1946	160	189,165	44,832						
145	Kincaid	Cisco, Pen	1946	40	5,302	279						
146	Leon	Gray, Pen	1949	30	4,327	4,327						
147	Merkel	Dothan, Per, Hope, Pen	1941	250	642,935	30,718						
148	Murphee	Cook, Pen	1946	540	400,360	73,198						
149	Patterson	Dothan, Per, Flippen, Pen	1947	330	175,184	73,808						
150	Pinckley	Ingram, Pen	1949	40	6,345	6,345						
151	Reddin	Dothan, Per, Flippen, Cook, King, Swastika, Pen	1942	1,960	4,403,514	800,315						
152	Reiderback	Cook, Flippen, Pen	1948	300	82,866	42,355						
153	Riney	Ingram, Pen	1949	90	38,175	38,175						
154	Salt Branch	Flippen, Pen	1949	150	28,530	28,530						
155	Southview	Flippen, Pen	1940	240	292,963	7,410						
156	Trent	Saddle Creek, Pen	1942	120	117,868	28,418						
157	Other Fields [14]	Per, Pen	1916	1,100	788,678	71,659						
158	Total Taylor County			6,750	7,870,040	1,758,019						
	Throckmorton											
159	Ault	Caddo, Pen	1944	400	170,754	24,952						
160	Mc Ketchan	Chappel, Mis	1948	80	89,845	72,984						
161	Mc Knight	Caddo, Pen	1941	280	212,675	25,145						
162	Mudge Sloan	Mississippian, Pen	1949	40	2,868	2,868						
163	Parrott	Caddo, Pen	1941	120	105,700	3,715						
164	Schlittler	Caddo, Pen	1948	120	53,378	33,854						
165	Swenson	Marble Falls, Cong, Pen	1949	80	5,058	5,058						
166	Other Fields [15]	Pen, Mis	1924	9,220	11,377,513	3,293,797						
167	Total Throckmorton County			10,340	12,017,791	3,462,373						
	Total North Central Texas			213,190	476,405,897[16]	21,133,076						

[1] Includes Blake, Byler, Byrd Store, Childress, Clarke, Buffalo, Carson, Cross Cut, Estes, Fry, George, Smith Ellis, Stover, Brown County Regular and other fields.
[2] Includes Hatchett, Isenhour, Mautray, Buwaldt, Cutbirth, Callahan County Regular.
[3] Includes North Novice and North Novice Gray.
[4] Includes Burkett, Eastland, Gunn, Gunn East, Hunter Hudson, Jennings, Mc Cain, Santa Anna, Stewardson, Coleman Regular.
[5] Includes De Leon, Gorman, and Comanche Regular.
[6] Includes Desdemona, Hilburn, Mangum, Pyoneer, Ramsour, Le Bay, Le Bay Deep, Eastland Regular and other fields.
[7] Includes Erath Regular and other fields.
[8] Includes Mc Cauley West Field.
[9] Includes Moody, Pardue, Strawn, Haskell County Regular.
[10] Includes Alexander, Amason, Appling, Guitar, Higgs, Noodle Beef Line, Sandy Ridge, Leaders, Myatt, Noodle Creek, Pleasant Hill, Prine, Roberts, Cooper, Summons Harvey, Sellers, Crane, Cranston Grove, Jones County Regular and other fields.
[11] Includes Ashland, Strawn, Terchanson, Loyd Dalton, Palo Pinto Regular and other fields.
[12] Includes Bluff Creek, Cook Elliot, Frye, Hope, Ibex, Newel, Petroleum Producers, Simmons Harvey, Tannehill, Matthews, Sanders Ellenberger, Shackelford County Regular and other fields.
[13] Includes Breckenridge, Caddo, Curry, Compton, Donnell, Eastwild, East Ibex, Eolian, North Harpersville, North Caddo Ellenberger, Northwild, Peeks, Phillips, South Ibex, Star Tip, Skeen Strawn, Stroud Deep, Tipton, Wild, Woodley-Thorps, Stephens County Regular and other fields.
[14] Includes Blair, Lake Kirby, Sambs, Sayles, Taylor County Regular and other fields.
[15] Includes Atkinson, Batchelor, Brown, East Parrott, Graham-Kelly, Manning Parrott, Mcknight West, Mudge Graham, Sharp, Stubblefield, Woodson Shallow, Wright, Throckmorton County Regular and other fields.
[16] Does not include cumulative total for Wise County as did last year's report. Wise County is now reported in "Development and Production in North Texas."

LINE NUMBER	NUMBER OF WELLS[c]			WELLS PRODUCING[f] DEC. 1949			RESERVOIR PRESSURE LB PER SQ INCH		SECONDARY RECOVERY[g]	CHARACTER OF OIL[h]		PRODUCING FORMATION					DEEPEST ZONE TESTED[n] TO END OF 1949	
	COMPLETED TO END 1949	1949		OIL		GAS	INITIAL	AVG./END 1949		GRAVITY A.P.I.	SULPHUR PER CENT	CHARACTER[i]	POROSITY PER CENT[j]	DEPTH TO TOP OF PRODUCING ZONE FT.[k]	PROD. THICKNESS AVG. FT.[l] NET	STRUCTURE[m]	NAME	DEPTH OF HOLE FT
		COMPLETED	ABANDONED	FLOWING	ARTIFICIAL LIFT													
129	2	2		2						43		L	P	4,220		A	Ell, Ord	4,310
130	16	1	1		3					35		L	P	3,550		A	Ell, Ord	4,731
131	3,805	23	44	86	581					36-43		S L	P	1,800	10-	A	Ell, Ord	5,150
												S L		4,500	50	M N		
132	3,940	63	60	141	626													
133	2		2		1					37		L	P	6,016		A	Ell, Ord	6,239
134	2		1		1					38		L	P	4,700		A	Can, Pen	4,757
135	2		1		2					39		L	P	5,151		A	Can	6,576
136	6		4		4													
137	10	6	2	2	6					42		S	P	2,197	37	A	Hope, Pen	2,700
												L		2,689	11			
138	13	1			2					38		S	P	1,760		N	Cisco, Pen	1,858
139	14	14		1	13					40		S	P	1,673		A		
140	5	1			5					43		L	P	2,457	6	A	Hope, Pen	2,700
141	1	1			1							S L	P	2,832		A	Canyon, Beef	2,835
142	27	16		2	25					41		S L	P	2,224		A	Hope, Pen	2,700
143	2	2			2					40		L	P	2,754	4	A		
144	9	3	5		4					40		L	P	2,700		A	Cisco, Pen	3,320
145	2		2							46		S	P	2,616		N	Cisco, Pen	2,710
146	1	1		1								S	P	4,034	13	N		
147	20		1		15					38		L	P	2,000		A	Cisco, Pen	2,900
														2,600				
148	18	2	1		16					41		L	P	2,735		A	Cisco, Pen	3,062
149	11		2		9					40		S	P	2,223		A	Wolfcamp, Pen	2,813
														2,574				
150	1	1			1					40		S	P	2,709		N		
151	97	13		100	45					40		S L	P	2,190		A	Cisco, Pen	2,907
														2,625				
152	10			1	9					43		S L	P	2,526	4	A	Cisco, Pen	2,808
														2,498				
153	3	3			3					42		S	P	2,728	4	N		
154	5	5			5					40		S	P	2,340		A		
155	13			3	8					43		L	P	2,329		A	Can, Pen	3,667
156	4				4					42		L	P	2,745		N	Cisco, Pen	3,200
157	55	1	49	6	30					35-41		S L	P	1,400		A	Pre-Can	6,396
														3,000				
158	321	70	62	116	203													
159	5				4					40		L	P	4,150		A	Marble Falls, Pen	4,477
160	2			2						44		L	P	4,480		A	Chap, Mis	4,510
161	7	1	7							40		L	P	4,023		A	Mis	4,764
162	1	1		1						41		L	P	4,498	6	A		4,508
163	3		3							40		L	P	4,000		A	Caddo, Pen	4,056
164	3	1			3					42		L	P	3,753	5	A	Ell, Ord	4,768
165	2	2			2					39				4,924		A		5,023
166	765	122	84	124	467					34-40		L	P	4,500		A	Ell, Ord	5,981
167	788	127	94	127	476													
	19,466	970	906	1,228	6,691													

TABLE 2 - SUMMARY OF DRILLING OPERATIONS IN NORTH CENTRAL TEXAS

IMPORTANT PRODUCING WILDCATS DRILLED IN 1949												
LINE NUMBER	COUNTY	LOCATION			TOTAL DEPTH, FT OR METERS	PRODUCING FORMATION	PRODUCING DEPTH	DRILLED BY	OIL U. S. BBL	CHOKE, FRACTIONS OF AN INCH	CASING	TUBING
		SURVEY	BLK.	SEC.								
1	Callahan	D & D A		45	1,981	Cross Plains Sand	1921-1930	Star Oil Co.	70	15/64	165	30
2	Callahan	Univ. Lds.		139		Morris Sand	2140-2153	B. F. Phillips	141	32/64	Packer	160
3	Coleman	J. T. Sanders		24		Morris Sand	2655-2665	J. R. Penn, et al	101	1/2	250	250
4	Coleman	Yancy		184		Fry Sand	3285-3310	Woods Drlg. Co.	108	20/64	Packer	80
5	Coleman					Palo Pinto Beef	3071-3114	Jay Mabee Drlg. Co.	203			
6	Coleman	S. Crooks				Brenner Sand	2100-2117	W. E. Stepp & L. J. Maxwell	134	3/4		
7	Coleman	M. A. Fisk				Marble Falls	2311-2355	Dunham & Young	410	10/64	600	800
8	Coleman	A. Williams		655		Marble Falls	2426-2440	Anzac Oil Corp.	154			
9	Coleman	J. R. Merrill				Fry Sand	3368-3373	H. B. Canby Drlg.	336	12/64	600	700
10	Comanche	Lampasas C S L		25		Miss. Beef	2525-2569	Sohio Petr. Co.	103	3/4	200	20
11	Eastland	H & T C	2	59	4,036	Mississippian	3987-4013	Lone Star Prod. Co.	292	3/8	430	140
12	Erath	Thos. Harrell				Ellenburger	3962-4002	Anburgey Bros., et al	41			
13	Fisher	T & P	19	11	5,170	Flippen	2865-2875	Skelly Oil Co.	97			
14	Fisher	H & T C	1	199	6,100	Swastika	3772-3780	T & P Coal & Oil	127	20/64		40
						Ellenburger	5948-5984		79	16/64	50	Packer

TABLE 2 - Continued SUMMARY OF DRILLING OPERATIONS IN NORTH CENTRAL TEXAS

IMPORTANT PRODUCING WILDCATS DRILLED IN 1949

LINE NUMBER	COUNTY	LOCATION			TOTAL DEPTH, FT OR METERS	PRODUCING FORMATION	PRODUCING DEPTH	DRILLED BY	OIL U. S. BBL	CHOKE, FRACTIONS OF AN INCH	CASING	TUBING
		SURVEY	BLK.	SEC.								
15	Fisher	S. A. Barnard				Canyon Sand	4723-4738	Woods Drlg. Co.	154	28/64		50-100
16	Fisher	El Paso C S L	317	27	4,047	Cook Sand	3594-3600	Lion Oil Co.	76			
17	Fisher	T. H. Crosby				Cook Lime	3556-3580	A. G. Hill & Walter Duncan	177			
18	Fisher	W. E. Richardson		9		Canyon Sand	4589-4630	Round Top Oil Co.	226	1/4	Packer	400
19	Fisher	H & T C	1	199		Canyon Sand	4422-4462	T & P Coal & Oil	121			
20	Haskell	F. Burchard				Strawn Sand	4772-4780	Pan Amer. Prod.	68			
21	Haskell	H & T C	45	239	5,199	Strawn Sand	5023-5027	Danciger Oil & Ref.	180			
22	Haskell	J. Korus			6,031	Strawn Sand	4735-4760	Humble Oil & Ref.	160	5/16	Packer	80
23	Haskell	T. D. Quiggs			3,624	Canyon Reef	3610-3615	Stanolind Oil Co.	151	10/64	55	120
24	Jones	M E P & P		2		Flippen	2640-2656	S. C. Herring	130	10/64	Packer	80
25	Jones	D & D A	1	25		Tannehill Sand	1629-1646	T. D. Humphrey	48	13/64	80	85
26	Jones	T N & O		13	4,390	Flippen	2395-2406	J. W. Gehle	45			
27	Jones	T & P	18	53		Hope Lime	2772-2776	Hoark, Hooker & West Central Drlg.	185			
28	Jones					Flippen	2088-2090	Ingren & Frazier	105			
29	Jones	De Witt C S L	150	24		Reef	4315-4322	Hoark, Hooker & Hoark	106	3/4	100	900
						Strawn Sand	4682-4702	Drillers	76	12/64		100
30	Jones	Goliad C S L				Gunsight	3152-3158	C. U. Bay & Taubert Drlg. Co.	146	1/2		
31	Jones	T & P	14	4		Upper Hope Sand	1830-1855	Manley Bros. & Barron	42			
32	Jones	J. W. Mc Kissick				Canyon Sand	3465-3615	Walter Duncan & A. G. Hill	24			
33	Jones	T & P	2	1		Unidentified Sand	2002-2010	Montray, Moore Drlg.	62		250-350	250
34	Nolan	T & P	19	44	5,735	Strawn Sand	5124-5131	Iowa Payne Oil Co.	46			
35	Nolan	T & P	23	67	7,155	Ellenberger	7097-7120	Skelly Oil Co	154			
36	Palo Pinto	P. Miller			1,781	Unidentified Sand	1766-1769	Ernest Loyd	65			
37	Parker	M. Waugh				Ellenberger	6658-6688	Buzz Morgan, et al	32	20/64	Packer	200
38	Shackelford	T E & L			4,451	Caddo Lime	3611-3615	G. E. Kadane & Sons	153	23/64	680	400
39	Shackelford	E T & R. R.				Cook Sand	1341-1349	Big West Drlg. Co.	72			
40	Shackelford	T E & L				Strawn Sand	2057-2080	G. E. Kadane, et al	78			
41	Shackelford	L A L		22	4,347	Conglomerate	4131-4146	Danciger Oil & Ref.	109	1/8	550	550
42	Shackelford	O A L		20		Ellenberger	4236-4270	Boeser & Pendleton	292	13/64	650	325
43	Shackelford	T E & L				Ellenberger	4376-4386	Oxford Drlg. Co.	210	12/64	1220	400
44	Shackelford	B O A		20		Ellenberger	4245-4258	M. J. Mitchell	120	1/4	600	500
45	Shackelford	E T B R	14	26		Cisco Series Sand	1621-1631	Humble Oil & Ref.	36			
46	Shackelford	B O A		20	4,305	Lake Sand	3937-3952	M. J. Mitchell	138	16-64	490	260
47	Shackelford	E T B R	1	126		Cisco Series Sand	1320-1328	Great Expectations Oil Co.	49			
48	Shackelford	E T B R		58		Tannehill Sand	887-905	H R H Drlg. Co.	35			
49	Shackelford	E T B R		194		Saddle Creek	1531-1537	Jack H. Moore	101			
50	Shackelford	Wm. Woodward		50		Lower Hope	992-996	P. S. Kendrick & M. E. Alsoton	64			
51	Stephens	T E & L				Mississippian	4230-4310	Bond Oil Co., et al	165	32/64	690	125
52	Stephens	S. P.	1	5		Caddo	4059-4095	Star Oil Co., Inc.	130	12/64	1050	850
53	Stephens	T & P	8	3		Ellenberger	4463-4488	Mc Elroy Ranch Co.	65	3/8	450	60
54	Stephens	T & P	8	3	4,480	Caddo	3249-3255	Mc Elroy Ranch Co.	116	10/64	860	250
55	Stephens	T & P	8	3		Caddo	4469-4470	Mc Elroy Ranch Co.	109	13/64	480	150
56	Stephens	T E & L		2965		Strawn Sand	1950-1966	Connally-Thornton	41	5/8		
57	Stephens	S P	2	18		Mississippian	4290-4310	T & P Coal & Oil Co.	129	12/64	525-200	725-425
58	Stephens	T E & L		1513	4,594	Mississippian	4388-4394	Mc Elroy Ranch Co.	181	1/8	1750	1250
59	Stephens	T & P	8	3	4,450	Caddo	3256-3262	Mc Elroy Ranch Co.	187	11/64	275	600
60	Stephens	T & P	8		4,565	Mississippian	4523-4543	Mc Elroy Ranch Co.	251	11/64	960	700
61	Stephens	Jas. Lee			3,229	Caddo	3205-3209	Mc Elroy Ranch Co.	112	10/64	790	540
62	Stephens	T & P	6	17	3,919	Marble Falls	3734-3744	T & P Coal & Oil Co.	193	3/4	1300	75
63	Taylor	Guadalupe			2,850	Ingram	2754-2758	West Central Drlg.	87			
64	Taylor	T & P	14	22	1,970	Saddle Creek	1673-1679	Twin Oil Corp., et al	63	1/2		
65	Taylor	Grimes C S L				Dothan Lime	2221-2231	Cross Central Pet.	121			
66	Taylor	Grimes C S L			2,808	Frazier	2736-2741	Geochemical Sur.	107	1/2		
67	Taylor	Grimes C S L			2,783	Cook Sand	2572-2576	Geochemical Sur.	330	16/64	Packer	50
68	Taylor	Grimes C S L			2,727	Ingram	2607-2613	Geochemical Sur.	123			
69	Taylor	J. C. Thompson			4,120	Gardner Sand	4103-4120	J. P. Prod. Co.	75	3/8		
70	Taylor	Grimes C S L				Ingram	2709-2713	Geochemical Sur.	102	1/2	Packer	30
71	Taylor	J. C. Thompson		433		Jennings Sand	4042-4044	Hiawatha Oil & Gas	77			
72	Throckmorton	W. S. Riddle			4,566	Conglomerate	4529-4553	Humble Oil & Ref.	215	12/64	480	250
73	Throckmorton	T E & L				Mississippian	4616-4626	James H. Snowden	208	1/2	700-220	720-180
74	Throckmorton	H B H & C		215		Caddo	4550-4555	Fred M. Manning	70			
75	Throckmorton	C. W. Marques				Canyon Sand	2808-2822	A. Kriss & H. Schwartz	480	3/4	300	100
76	Throckmorton	T E & L				Mississippian	4463-4480	Woodley Pet. Co.	175	10/64	1220	560
77	Throckmorton	T E & L				Mississippian	4609-4632	Woodley Pet. Co.	152	10/64	1040	675
78	Throckmorton	T E & L		2315		Mississippian	4621-4630	James H. Snowden	132	1/2	700-175	875-175
79	Throckmorton	H B H & C		248	4,987	Marble Falls, Gaggio.	4895-4905	Fred M. Manning	155	12/64	900	175
80	Throckmorton	T E & L		686		Mississippian	4613-4621	James H. Snowden	125	3/8	650-375	800-525
81	Throckmorton	T E & L		934	4,598	Mississippian	4418-4424	Woodley Pet. Co.	63	12/64	1500	810
82	Throckmorton	T E & L				Caddo	4549-4550	Deep Rock Oil Corp.	52			
83	Throckmorton	T E & L				Mississippian	4474-4510	Turner & Duval	149	14/64	675	585
84	Throckmorton	T E & L			4,500	Mississippian	4498-4504	Mudge Oil Co.	119	12/64		
85	Throckmorton	T E & L		2227		Strawn Sand	3407-3470	Kingery & Patterson	117			
86	Throckmorton	T E & L		1614	4,974	Strawn Sand	3566-3576	Rock Hill Oil Co.	75			
87	Throckmorton	T E & L		3001	4,769	Mississippian	4487-4493	Dwight M. Bess	120	10/64	Packer	450
88	Throckmorton	T E & L		2237		Mississippian	4565-4596	Warren Oil Corp.	290	12/64	840	780

TOTAL NORTH CENTRAL TEXAS DISTRICT

Number of wells drilling Dec. 31, 1949 167
Number of wells completed during 1949 970
Number of gas wells completed during 1949 324
Number of dry holes completed during 1949 794

UNIV. TEXAS BULL. 3232			M.G. CHENEY, A.A.P.G. BULL., VOL. 24, NO. 1 (1940) VOL. 29, NO. 2 (1945)				
	GROUP	FORMATION	SERIES	GROUP	FORMATION (EQUIVALENT)	IMPORTANT MEMBERS	
PERMIAN	DOUBLE MOUNTAIN	WHITEHORSE	GUADALUPE	WHITEHORSE			PERMIAN
		BLAINE		EL RENO (SAN ANDRES)	DOG CREEK SH BLAINE GYP FLOWER-POT SH SAN ANGELO SS		
		SAN ANGELO					
	CLEARFORK	CHOZA	LEONARD	CLEAR FORK	CHOZA	WEINELL DOL	
		VALE			VALE	BULLWAGON DOL	
		ARROYO			ARROYO	STANDPIPE LS LYTLE LS RAINY LS	
	WICHITA	LUEDERS		LUEDERS	LAKE KEMP MAYBELLE LS PAINTROCK LS		
		CLYDE		CLYDE	TALPA GRAPE CREEK		
		BELLE PLAINS		BELLE PLAINS x	BEAD MOUNTAIN VALERA SH & ANHYDRITE JAGGER BEND LS ELM CREEK LS JIM NED SH +	BEAVERBURK	
		ADMIRAL	WOLFCAMP	ADMIRAL x	FISK + HORDS CREEK x		
		PUTNAM		PUTNAM	COLEMAN JUNCTION x SANTA ANNA BRANCH+		
		MORAN		MORAN	SEDWICK + "HORSE CREEK" x "DOTHAN" x		
PENNSYLVANIAN	CISCO	PUEBLO	CISCO x	PUEBLO x	CAMP COLORADO x	COON MOUNTAIN SS	
					STOCKWETHER x	WALDRIP LS. NO. 3	
					SADDLE CREEK x	WALDRIP LS. NO. 2 WALDRIP LS. NO. 1	
		HARPERSVILLE		THRIFTY x	OBREGON +	WALDRIP-NEWCASTLE COALS	
					CHAFFIN x (CRYSTAL FALLS) BRECKENRIDGE x SPECK MOUNTAIN (BLACH RANCH)x IVAN (ROCKY MOUND) BELLEROPHON)x AVIS SS	PARKS-MOUNTAIN SS	
		THRIFTY					
		GRAHAM		GRAHAM	WAYLAND SH GUNSIGHT LS (CYCLE 9?) POST-BUNGER CYCLES 1-7 x BUNGER x NORTH LEON x		
					GONZALES x	"UPPER LS" SALEM SCHOOL LS KISINGER CHANNEL	
	CANYON	CADDO CREEK	CANYON x	CADDO CREEK	HOME CREEK LS HOG CREEK SH		
		BRAD		BRAD	RANGER LS PLACID SH (SEAMAN RANCH)		
		GRAFORD		GRAFORD	WINCHELL	"LIMESTONES 1-4"	
					CEDARTON SH ADAMS BRANCH) (WOLF MOUNTAIN)	"FUSILINID BED" DALTON COAL	
		PALO PINTO		WHITT +	PALO PINTO x	"FUSILINID BED" WILES LS FOSIDEON SH WYNN LS x ---------SS	PENNSYLVANIAN UPPER
					KEECHI CREEK x	---------LS ---------LS TURKEY CREEK LS	
	STRAWN	MINERAL WELL			SALESVILLE x	---------SS ---------LS ---------SS DOG BEND LS LAKE PINTO SS	
		GARNER	STRAWN x	LONE CAMP +	EAST MOUNTAIN SH	VILLAGE BEND LS (UPPER PART CAPPS LS) NOE MOUNTAIN SS	
					GARNER	BRAZOS R.-RICKER QS MINGUS SH & SS THURBER COAL	
		MILLSAP LAKE		MILLSAP LAKE **	GRINDSTONE CREEK	GOEN LS. RICKER STA. LS SANTO LS "DUCK CREEK SS"	
					LAZY BEND **	BRAWNON BRIDGE LS MILL CREEK	
	BEND	SMITHWICK	LAMPASAS +	KICKAPOO CREEK **	RATVILLE **	DENNIS BRIDGE KICKAPOO FALLS DICKERSON	MIDDLE
					PARKS +		
					CADDO POOL +	"CADDO" LIME	
		MARBLE FALLS		BEND	SMITHWICK	BEND SUBSURFACE	
				ATOKA EQUIV.	BIG SALINE x	MARB. FALLS	
			MORROW		SLOAN ***		LOWER
MISS	CHESTER OSAGE	BARNETT	CHESTER-MER?		BARNETT		MISS
		CHAPPEL	OSAGE		CHAPPEL		
ORD	ELLENBURGER	COT-JEFF CITY ROUBIDOUX GASCONADE		ELLENBURGER	EQUIV. COTTER-JEFF CITY-HONEYCUT + ROUBIDOUX GORMAN GASCONADE TANYARD	STAENDEBACH DOL LS." THREADGILL LS. DOL	ORD
CAMBRIAN		EMINENCE POTOSI			EMINENCE POTOSI WILBERNS *	PEDERNALES DOL SAN SABA LS POINT PEAK SH MORGAN CK LS WELGE SS	CAMBRIAN
		SIGNAL MT. FORT SILL WILBERNS CAP MT. HICKORY			SAN SABA WILBERNS CAP MOUNTAIN HICKORY RILEY *	LION MT SS CAP MT LS HICKORY SS	

* NEW NAMES x REDEFINED —— CHANNEL AND SANDSTONE DEPOSITS (BULL A.A.P.G. VOL. 24 NO. 1)
+ CAMBRIAN ORDOVICIAN OF CLOUD, BARNES AND BRIDGE JUNE 1945 UNIV. TEX. PUB. 4301
++ REVISED DEC. 1946, M.G.C. +++ F.B. PLUMMER UNIV. TEX. PUB. 4401

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Oil And Gas Developments In South Central Texas During 1949

By WM. H. SPICE, JR.,* Member AIME

Drilling activities during 1949 continued to increase in South Central Texas, which comprises the 30 counties in District No. 1, Oil and Gas Division, Railroad Commission of Texas. This increase continued a trend started during 1948 and resulted in the discovery of 11 new oil fields, which was two more than was discovered in the previous year.

There were a total of 552 wells drilled during 1949, compared with 519 wells drilled in 1948, which is a 6 per cent increase in drilling activity. A greater proportion of wildcat wells was drilled during 1949, with 238 wells being exploratory tests and 314 being field wells. This is a proportion of 56 per cent field wells to 43 per cent wildcats as against 62 per cent field wells and 38 per cent wildcats during 1948. A total of 242 tests were completed as oil wells, including the 11 new oil field discoveries, seven tests were completed as gas and gas-condensate wells and 303 tests were abandoned as non-producers, which is an increase proportionately in failures over the previous year. Atascosa County again led the district in number of wells drilled with a total of 107. Caldwell County was second with 87 and Frio and Guadalupe Counties were third with 61 wells each. These four counties accounted for about 57 per cent of the drilling activity during the year with the remaining wells being drilled in 18 other counties throughout the district.

DISCOVERIES

In general, the newly discovered fields were all of minor importance and probably will not prove to add materially to the oil reserves of the district.

The Big Foot Field in Frio County was a new Navarro sand discovery, located considerably updip from the Charlotte-Pearsall trend through this area. The Divot Field in the same county is a new Austin chalk discovery located to the southwest of the Pearsall (Austin Chalk) Field. The Wintergarden Field in Dimmit County was a Navarro sand discovery in the Carrizo Springs area in the southwestern part of the district.

The Marsha Field in Bastrop County and the Southwest Byersville and South Coupland Fields in Williamson County are new discoveries from Dale limestone and the Lund Field in Travis County is a newly discovered serpentine intrusion. In Guadalupe County, the Jayeddie Field is a new discovery in the Austin chalk and the Wolf Creek Field is a discovery in the Buda limestone. The Lane Field in Caldwell County is also an Austin chalk discovery. These seven discoveries are all located along the Balcones fault line trend and are of minor importance.

One new Wilcox (Eocene) discovery was made in the Green Franklin Field in Mc Mullen County and an extension of over a mile was made in the Loma Alto-Wilcox Field in the same county.

EXPLORATORY DRILLING

The few exploratory tests which contributed materially to the geologic information of the district are listed in Table 2, together with the successful exploratory wells which resulted in new discoveries.

PRODUCING WELLS

The district had a total oil production of 9,500,084 bbl for the year 1949, with a total of 3,568 wells producing during December of that year. Produced during the year from 41 gas-condensate wells were 5,883 mmcf of gas and 12,133 bbl of condensate. This is a decrease in oil production of about 4 per cent under the 1948 production and an increase in gas production of about 8 per cent over the previous year. Average daily oil production per producing well was 7.3 bbl during 1949 as against 7.9 bbl during 1948. The total of 3,568 producing oil wells at the end of 1949 compares with 3,424 producing oil wells at the end of 1948. A total of 242 new oil wells were completed and 112 producers have been shut in or abandoned during the year.

A total of 4,412,261 bbl of the total production of the district, or 46 per cent, was produced from the four old Edwards limestone fields, Luling, Branyon, Salt Flat and Darst Creek, which were discovered between 1922 and 1930. These four old fields still contribute about the same percentage of the total production of the district as they have for the past several years and to date have produced a total of about 212 million bbl or 75 per cent of the total oil produced to date in this district. Drilling in the proven fields was at about the same rate as during the previous year and the percentage, for the field wells, of producing oil and gas wells out of total wells drilled, was 76 per cent which was a slight decrease from the previous year. For the second successive year, the Charlotte Field in Atascosa County had the greatest number of producing wells drilled during the year with a total of 68 completions. The old Luling Field in Caldwell County had a total of 33 completions during the year and the shallow Gas Ridge Field in Bexar County had 29 new oil wells completed. The Pearsall (Austin Chalk) Field in Frio County had 21 successful completions and the shallow Elm Creek Field in Guadalupe County had a

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total of 20 new oil wells during the year. The Weigang Field in Atascosa County was extended in both a northeast and southwest direction with 12 new oil completions during the year. These six fields accounted for a total of 183 wells completed during the year or 58 per cent of total field wells drilled and the remaining field wells were drilled in 23 other fields located in 11 counties scattered throughout the district. There were 20 field wells and 26 wildcat tests drilling at the end of the year which is only 12 tests less than were being drilled at the end of the previous year.

EXPLORATION

At the end of 1949 there were no new producing trends developed in the district and there did not appear to be any change in the exploratory pattern for this area. In order of their importance, exploration is expected to continue along the following trends. (1) Further exploration for Navarro sand production along the general Charlotte-Pearsall trend in the western part of the district, (2) continued exploration along the Luling-Darst Creek trend in the fault line area of the eastern part of the district with production expected from Austin chalk, Dale limestone and serpentine and Edwards limestone between the depths of 700 ft and 3,000 ft, (3) exploration along the Wilcox (Eocene) trend in the southern part of the district with some deeper Edwards limestone tests along the shallower part of this trend, and (4) renewed exploratory activity on the Edwards Plateau in the northwestern part of the district for possible Pennsylvanian and Ordovician production.

ACKNOWLEDGMENTS

The author greatly appreciates the excellent cooperation of the Oil and Gas Division, Railroad Commission of Texas, and the numerous companies and individuals who furnished much of the production and well data shown in Tables 1 and 2 and acknowledges with appreciation the very able assistance of his associates who made it possible to prepare this paper.

FIG. 1 - LOCATION OF OIL AND GAS FIELDS - SOUTH CENTRAL TEXAS

TABLE I - OIL AND GAS PRODUCTION STATISTICS FOR SOUTH CENTRAL TEXAS IN 1949

LINE NUMBER	FIELD (County)[A]	PRODUCING FORMATION NAME AND AGE[B]	YEAR OF DISCOVERY	OIL PRODUCTION			GAS PRODUCTION			GAS/OIL RATIO[D] MCF/BBL	CONDENSATE PRODUCTION Thousands of Bbl	
				AREA PROVED ACRES	BARRELS TO END OF 1949	BARRELS DURING 1949	AREA PROVED ACRES	MILLION CU FT[C] TO END OF 1949	MILLION CU FT[C] DURING 1949		TO END OF 1949	DURING 1949
1	Adams,* *Medina*	Navarro and Taylor sands, Cre U	1926				2,000	x				
2	Alta Vista, *Bexar* [1]	Navarro sands, Cre U	1912	300	128,598							
3	Bear Creek, *Medina*	Navarro sands, Cre U	1947	30	1,940	814						
4	Bee Creek, *Caldwell*	Dale ls & Serp, Cre U	1940	320	313,825	5,125						
5	Big Foot, *Frio*	Navarro sand, Cre U	1949	200	9,833	9,833						
6	Billy Holland, *Edwards* [20]	Glen Rose ls, Cre L	1948	10								
7	Branyon, *Caldwell* [2]	Austin chalk, Cre U Edwards ls, Cre L	1930	900	3,624,976	78,144						
8	Buchanan, *Caldwell*	Serpentine, Cre U	1928	250	587,798	15,801						
9	Burdette Wells, *Caldwell* [3]	Edwards ls, Cre L	1936	200	60,848							
10	Byersville, *Williamson* [4]	Serpentine, Cre U	1933	370	666,684	9,848						
11	Byersville, Southwest, *Williamson*	Dale ls, Cre U	1949	40	3,852	3,852						
12	Callihan, SE *Mullen* [5]	Mirando, Govt. Wells, Pettus, Lana Novio, Eoc.	1918	500	1,329,189	47,956						
13	Calvert, *Milam* [6]	Navarro sands, Cre U	1945	x	x	x						
14	Campana, SE *Mullen* [7]	Govt. Wells, Eoc	1938	10	831		20	10.99	10.99			
15	Campana, South, SE *Mullen*	Cole Govt. Wells, Eoc Pettus	1941	780	841,506	121,817	100	x	470.36			
16	Carrizo, *Dimmit*	Navarro sands, Cre U	1941	20	9,268	1,174	120	138.80	138.80			
17	Carrizo Park,* *Dimmit*	Navarro sands, Cre U	1945	40	727		80	x				
18	Carroll, *Bastrop*	Serpentine, Cre U	1932	100	101,547							
19	Catarina, *Dimmit* [20]	Navarro sand, Cre U	1948	20	250	150						
20	Cedar Creek, *Bastrop* [8]	Serpentine, Cre U	1932	100	318,115	18						
21	Chapman, *Williamson*	Serpentine, Cre U	1928	450	4,699,326	33,659						
22	Charlotte, *Atascosa*	Navarro sand, Cre U Edwards ls, Cre L	1946 1944	4,400 220	4,782,293	2,020,088	80	1,029.45	260.27			
23	Charlotte, West, *Frio*	Navarro sand, Cre U	1948	120	26,258	26,258						
24	Chicon Lake, *Medina*	Navarro sand, Cre U	1929	450	169,395	8,835						
25	Chittim,* *Maverick*	Glen Rose limestone Cre L	1929				100	20,358.63	703.28		x	2,104
26	County Line,* SE *Mullen*	Cole, Eoc	1946				40	10.33	10.33			
27	Coupland, South, *Williamson*	Dale ls, Cre U	1949	20	613	613						
28	Crowther, SE *Mullen* [9]	Diboll, Eoc	1945	80	25,000							
29	Dale, *Caldwell* [10]	Dale ls, Serp, Cre U	1927	840	1,860,662	24,747						
30	Darst Creek, *Guadalupe*	Edwards ls, Cre L	1928	1,920	71,887,941	2,509,392						
31	Darst Creek Ext. (Clark), *Guadalupe*	Austin chalk, Cre U	1935	200	408,775	1,305						
32	Day, *Guadalupe* [11]	Austin chalk, Cre U Buda ls, Cre L	1940	20								
33	Del Monte, *Zavala*	Navarro sands, Cre U	1947	120	21,691	4,066	120	41.58	7.43			
34	Divot, *Frio*	Austin chalk, Cre U	1949	80	1,986	1,986						
35	Doering Ranch, *Frio*	Austin chalk, Cre U	1948	20	3,429	3,067	80	193.03	193.03			
36	Dunlap, *Caldwell* [12]	Austin chalk, Cre U	1930	120	456,349	9,965						
37	Dunlay, *Medina* [13]	Serpentine, Cre U	1938	30	1,988							
38	Eckert, *Bexar*	Navarro sands, Cre U	1927	850	1,056,004	13,837						
39	Elgin, *Bastrop* [7]	Austin chalk, Cre U	1941	10	3,565							
40	Elm Creek (Lavernia), *Guadalupe*	Navarro sands, Cre U	1939	450	116,954	22,404						
41	Ezzell, SE *Mullen, Live Oak*	Lana Novio, Eoc	1937	1,540	4,222,984	153,083	40	x				
42	Gas Ridge, *Bexar* [14]	Navarro sands, Cre U	1912	400	203,766	23,154	900	x				
43	Gause, *Milam* [15]	Edwards ls, Cre L	1948	10	629							
44	Green Branch, SE *Mullen*	Hecklaw, Eoc	1942	300	503,925	269,404						
45	Green Franklin, SE *Mullen*	Wilcox, Eoc	1949	80	2,643	2,643						
46	Hilbig, *Bastrop* [7]	Serpentine, Cre U	1932	260	3,173,475	126,457						
47	Holmes Ranch, *Edwards* [20]	Glen Rose ls, Cre L	1947	200	581							
48	Imogene, *Atascosa*	Edwards ls, Cre L	1942	1,240	1,128,900	130,404	40	x	382.30			
49	East Imogene, *Atascosa*	Edwards ls, Cre L	1947	80	24,929	10,716	20	x	32.61			
50	Jacob, SE *Mullen* [13]	Mirando Pettus, Eoc Yegua sands	1926	1,300	2,215,333	75,170						
51	Jaywalkie, *Guadalupe*	Austin chalk, Cre U	1949	40	15,308	15,308						
52	Jim Smith, *Bastrop*	Serpentine, Cre U	1948	20	5,070	1,022						
53	Joliet, *Caldwell*	Austin chalk, Cre U Edwards ls, Cre L	1947	220	233,763	75,002	40	4.82	4.82			
54	Jones, *Bexar*	Navarro sands, Cre U	1921	20	3,678	92						
55	Jourd (Skinny Ranch), SE *Mullen* [16]	Lana Novio, Eoc	1946	20	777							
56	Jourdanton, *Atascosa*	Edwards ls, Cre L	1945	1,900	1,264,942	398,728	40	982.49	540.49			
57	Kumbro, *Travis*	Serpentine, Cre U	1935	40	12,589	3,289						
58	Lane, *Caldwell*	Austin chalk, Cre U	1949	20	1,407	1,407						
59	La Coste (Fairfield), *Bexar* [14]	Anacacho ls, Cre U	1939	40	7,179	487	60	x	11.83			
60	Larremore, *Caldwell*	Edwards ls, Cre L	1927	100	386,934	18,816						
61	Lentz, *Bastrop*	Dale ls, Cre U	1941	60	79,153	9,021						
62	Leona River,* *Zavala*	Navarro sands, Cre U	1945				120	85.58				
63	Little Alamo, SE *Mullen*	Queen City & Carrizo, Eoc	1947	120	53,822	12,822						
64	Lana Alto, SE *Mullen*	Chernosky, Eoc	1935	80	263,628	9,653						
65	Lana Alto-Wilcox, SE *Mullen*	Wilcox, Eoc	1944	320	266,233	44,395			315.66			
66	Lone Oak, *Bexar* [17]	Navarro-Taylor, Cre U	1934	10	4,485							

LINE NUMBER	NUMBER OF WELLS[d]			WELLS PRODUCING[f] DEC. 1949			RESERVOIR PRESSURE LB PER SQ INCH		SECONDARY RECOVERY[g]	CHARACTER OF OIL[h]		PRODUCING FORMATION					DEEPEST ZONE TESTED[n] TO END OF 1949	
	COMPLETED TO END 1949	1949		OIL		GAS	INITIAL	AVG. /END 1949		GRAVITY A.P.I.	SULPHUR PER CENT	CHARACTER[i]	POROSITY PER CENT[j]	DEPTH TO TOP OF PRODUCING ZONE FT[k]	PROD. THICKNESS AVG. FT / NET	STRUCTURE[l]	NAME	DEPTH OF HOLE, FT
		COMPLETED	ABANDONED	FLOWING	ARTIFICIAL LIFT													
1	58						x	x		Gas		S-Sh	P	900	x	F	Travis Pk. Schist	5,512
2	41			Abd - 1948			x			35	0.3	S	15-20	220	20	F	Travis Peak	4,535
3	3			2	1		x	x		37		S-Sh	P	2,240	10	M L	Navarro sand	2,620
4	33				8		x	x		39		L-Serp	P	2,050	x	Intn	Austin chalk	2,250
5	7	7			7		x	x		43		S	P	3,315	30	M L	Navarro sand	3,701
6	1		1	Abd - 1949			x	x		18		L	P	530	11	x	Glen Rose ls	1,166
7	187				108		x	x		37	0.8	L	P	1,816	x	F	Edwards ls	2,450
8	41				21		x	x		32	0.2	Serp	12	1,740	x	Intn	Edwards ls	2,483
9	12			Abd - 1947			200	x		36	0.8	L	Fis	2,210	15	F	Edwards ls	2,420
10	41		1		36		x	x	G	37	0.2	Serp	P	830	x	Intn	Edwards ls	2,000
11	2	2			2		x	x		36		L	P	1,115-1,159	x	Intn	Serpentine	1,275
12	150			1	64		x	x		20		S	P	848 1,030	15 10	M L F	Carrizo sand	5,301
13	x	x	x	x	x		500	x		Gas 36		S	P	1,221 2,014	10 5	M L F	Navarro sand	2,202
14	1			Oil prod. Abd - 1942 producing gas			x	x		24		S	P	2,492	20	M F	Pettus	3,102
15	33			5	25	3	x	x		Gas 21-23		S S	P P	1,864 2,554 3,012	3 10 12	M F	Cook Mountain	4,486
16	4			2	1	3	x	x		Gas		S	17-21	2,190 2,222	16 6	F	Taylor	3,312
17	2						x	x		Gas 38		S	P	2,710	7	A	Edwards ls	7,550
18	9			Abd - 1942			x	x		36		Serp	12	2,300	78	Intn	Edwards ls	2,919
19	1		1	Abd - 1949			x	x		42		S-Sh	P	4,900	32	F	Navarro sand	5,210
20	14			Abd - 1946			100	x		35	0.2	Serp	15-20	1,630	50	Intn	Edwards ls	2,300
21	70		1		69		400	x		36	0.2	Serp	20	1,750	20	Intn	Edwards ls	3,226
22	257	68		110	143		x	x		35		S	28	5,154	45	M F	Edwards ls	7,281
	13			7	6		x	x		38		L	P	6,904	8	M F		
23	6	4		3	2		x	x		30		S	P	5,576	20	M F	Navarro sand	5,742
24	84				69		x	x		21	0.1	S	15	260	20	D	Edwards ls	1,725
25	5					3	2,000	x		Gas 42-45		D	P	5,650	x	A F	Travis Peak	7,635
26	1					1	630	x		Gas		S	P	1,926	47	F	Pettus	3,176
27	1	1			1		x	x		36		L	P	1,006	28	Intn	Serpentine	1,330
28	23			Abd - date x			x	x		18		S	P	500	10	M L	Cook Mt.	2,000
29	72				52		150	x		37	0.2	L-Serp	15	1,915	30	Intn	Edwards ls	2,661
30	368		6	3	310		350	x		36	0.8	L	P	2,650	30	F	Travis Pk. Schist	5,509
31	11				1		200	x		33.6	0.5	C	Fis	2,375	100	F	Edwards ls	3,200
32	2			Abd - 1940			150	x		36		C-L	P	2,377	x	F	Edwards ls	2,830
33	7	2		1	2	2	1,400	x		Gas 25		S	P	3,308	40	F	Taylor	4,302
34	2	2			2		x	x		33		C	F	5,533	x	A F	Edwards ls	6,705
35	3	2				2	x	x		29		C	Fis	5,399	77	F	Edwards ls	6,645
36	20				9		400	x		36		C	Fis	2,375	15	F	Edwards ls	2,420
37	1			Abd - 1940			x	x		21		Serp	P	542	x	Intn	Austin chalk	851
38	121				92		x	x		34	0.3	S	16	620	10	F	Edwards ls	1,590
39	1			Abd - 1942			x	x		36		C	Fis	2,820	20	F	Edwards ls	3,352
40	87	20	14		47		x	x		40-42		S-Sh	P	700	x	T	Navarro	800
41	156				111		x	x	G	20		S	P	1,490	11	M L	Cook Mt.	3,180
42	211	29	4		128		x	x		22	0.4	S	15-20	230	15	A F	Pre-Cretaceous	7,190
43	1			Abd - 1949			x	x		30		L	P	5,697	7	F	Edwards ls	5,753
44	10	1			10		x	x		28.2		S	P	3,935	x	F	Navarro	7,632
45	2	2		2			x	x		38		S	P	5,085	20	T	Wilcox	5,792
46	14			12			1,240	x	P	37	0.2	Serp	12	2,450	50	Intn	Edwards ls	3,250
47	10			Abd - 1949			x	x		14		L	x	548	32	x	Glen Rose ls	1,010
48	31			17	12		3,280	x		19		L	P	7,570	30	F	Glen Rose ls	9,390
49	4			4			3,600	x		33		L	P	8,003	10	F	Edwards ls	8,124
50	139				60		x	x		Gas 21.5		S	P	1,050	8 7	M L	Mt. Selman	3,171
51	4	4			3		x	x		20.5 29		C	F	2,011	8 54	F	Austin chalk	2,181
52	2				2		x	x		37		Serp	P	1,615	32	Intn	Serpentine	1,647
53	22	5	3	2	15	1	x	x		35		C	Fis	1,901	128	F	Edwards ls	2,518
54	3			Abd - 1946			x	x		x		L S-Sh	P	2,159 600	4 x	T	Edwards ls	2,008
55	2			Abd - 1949			x	x		x		S	P	1,382	x	M L	Lima Nuvio sd	1,398
56	55	8		48	2		x	x		39		L	P	7,383	30	F	Edwards ls	7,468
57	4				2		x	x		36.5		Serp	P	660	x	Intn	Edwards ls	1,280
58	1	1			1		x	x		41		C	F	1,603	34	F	Austin chalk	1,637
59	5				1	3	x	x		31		L	P	1,150	x	N	Edwards ls	1,600
60	20				7		x	x		23		L	P	1,285	35	F	Travis Pk.	3,360
61	3				3		x	x		36		L	P	2,226	18	F	Austin chalk	2,453
62	3						1,680	x		Gas		S	P	4,224	17	M C	Taylor (San Miguel)	4,933
63	6	1	1	1	4		x	x		18.4		S	P	2,386	7	F	Carrizo-Wilcox	4,110
										28				4,074	8			
64	5				2		x	x		21		S	P	2,195	12	M L	Cockfield	2,766
65	8	1		6			x	x		37		S	P	6,838	30	A F	Wilcox	9,620
66	1			Abd - 1940			x	x		33.4		S	P	1,480	18	F	Edwards ls	2,255

TABLE 1 - Continued OIL AND GAS PRODUCTION STATISTICS FOR SOUTH CENTRAL TEXAS

LINE NUMBER	FIELD (County)[a]	PRODUCING FORMATION NAME AND AGE[b]	YEAR OF DISCOVERY	OIL PRODUCTION			GAS PRODUCTION			GAS/OIL RATIO[d] MCF/BBL	CONDENSATE PRODUCTION Thousands of Bbl	
				AREA PROVED ACRES	BARRELS TO END OF 1949	BARRELS DURING 1949	AREA PROVED ACRES	MILLION CU FT[c] TO END OF 1949	MILLION CU FT[c] DURING 1949		TO END OF 1949	DURING 1949
67	Luling, *Caldwell-Guadalupe*	Edwards ls, Cre L	1922	2,200	88,807,561	1,368,146	30	x	56.15			
68	Lund, *Travis*	Serpentine, Cre U	1949	20	263	263						
69	Lytton Springs, *Caldwell*	Serpentine, Cre U	1925	1,360	9,235,211	75,890		x	4.23			
70	Manda, *Travis*	Serpentine, Cre U	1935	40	25,265							
71	Mannford, *Guadalupe*	Austin chalk, Cre U	1929	40	454,677	5,182						
72	Marsha, *Bastrop*	Dale ls, Cre U	1949	20	2,959	2,959						
73	Mc Knight Ranch,* *Dimmit*	Navarro sands, Cre U	1945				40	x				
74	Minerva-Rockdale, *Milam* [16]	Navarro sands, Cre U	1921	4,250	4,126,193	48,252	10	x				
75	Mull, *Atascosa*	Edwards ls, Cre L	1945	120	33,907	4,522						
76	Munson, *& Mullen*	Mirando, Eoc	1938	180	252,124	5,266						
77	Nash Creek, *Guadalupe* [13]	Taylor-Marl, Cre U	1936	10	46,535							
78	Pearsall-Austin Chalk, *Frio*	Austin chalk, Cre U Buda ls, Cre L	1933	1,000	1,682,607	217,034						
79	Pearsall-Navarro Sand, *Frio*	Navarro sand, Cre U	1935	1,080	2,979,177	357,067	1,250	3,231.99	1,543.35			
80	Pendencia Creek,* *Dimmit*	Navarro sand, Cre U	1941				1,320	x				
81	Philtop, *Bexar* [11]	Austin chalk, Cre U	1938	40	8,171							
82	Poteet, *Atascosa*	Anacacho ls, Cre U	1948	10	14,009	12,571						
83	Quinsache, *La Salle* [17]	Carrizo, Eoc	1947	10	390							
84	Rainbow Bend, *La Salle*	Lower Wilcox, Eoc	1947	40	5,179	798						
85	Rhode,* *& Mullen*	Cole, Eoc	1936				1,200	x	730.27			
86	Riddle, *Bastrop*	Austin chalk, Serpentine, Cre U	1938	50	141,457	5,437						
87	Salt Flat, *Caldwell*	Edwards ls, Cre L	1928	1,300	47,663,254	456,579		x				
88	San Caja,* *& Mullen & Live Oak*	Wilcox sands, Eoc	1944				1,320	2,487.79	426.09		x	10,029
89	San Jose, *& Mullen*	Cole, Eoc	1938	130	16,899	9,380	20	x	4.65			
90	San Miguel, *& Mullen*	Wilcox sand, Eoc	1948	40	13,471	12,327						
91	Seguin, *Guadalupe*	Buda ls, Cre L	1948	20	810	210						
92	Somerset, *Atascosa & Bexar*	Navarro, Taylor, Cre U	1912	11,390	11,464,738	42,912						
93	Southton-Yturria, *Bexar*	Navarro sands, Cre U	1921	650	768,574	9,200						
94	Spiller, *Guadalupe*	Buda ls, Cre L	1938	30	41,863	2,799						
95	Staples, *Caldwell & Guadalupe* [19]	Austin chalk, Cre U	1934	60	3,845	1,548						
96	Taylor-Ina, *Medina*	Navarro sands, Cre U	1922	x	163,377	115						
97	Tenney Creek, *Caldwell*	Austin chalk, Cre U Buda ls, Cre L	1940	150	529,677	10,789						
98	Thrall, *Williamson*	Serpentine, Cre U	1914	475	2,640,969	20,250		x	4.43			
99	Turney, *Edwards*	Glen Rose, Cre L	1946	50	148	79						
100	United, *Guadalupe* [20]	Austin chalk, Cre U	1944	40	17,450							
101	Van Cleve,* *Zavala*	Navarro sands, Cre U	1944				40	x				
102	Von Ormy, *Bexar*	Navarro sands, Cre U	1933	650	894,902	11,129	40	x	.12			
103	Walnut Creek, *Caldwell*	Serpentine & Dale lime, Cre U	1938	80	13,119	868						
104	Wardlaw, *Edwards*	Glen Rose, Cre L	1947	140	9,240	2,480						
105	Washburn, *La Salle* [18]	Wilcox sands, Eoc	1940	520	1,888,769	157,953	40	x	32.29			
106	Weigang, *Atascosa*	Carrizo, Eoc	1946	780	1,366,868	383,118						
107	Wentz,* *& Mullen*	Cole, Eoc	1932				80	x				
108	Wintergarden, *Dimmit*	Navarro (Olmos) Sand, Cre U	1949	20	4,986	4,986						
109	Wolf Creek, *Guadalupe*	Austin chalk, Cre U Buda ls, Cre L	1949	60	5,615	5,615						
110	Yost, *Bastrop*	Serpentine, Cre U	1928	120	973,388	5,660						
111	Zoboroski, *Guadalupe*	Austin chalk, Cre U	1935	180	320,872	10,843	20	x	.12			
	TOTALS:			50,365	283,718,748	9,500,084	9,410	x	5,883.90			12,133

* Gas field only.

[1] Includes Degree, abandoned 1948; Alta Vista abandoned 1943.
[2] Includes Ellison-Young.
[3] Northeast Luling; abandoned 1947.
[4] Includes Mathews and Noack; Byersville abandoned, date x.
[5] Includes South Callihan.
[6] Extension of Calvert Field, Robertson County.
[7] Abandoned 1942.
[8] Abandoned 1946, now includes North Cedar Creek.
[9] Abandoned, date x.
[10] Includes West Dale and North Dale (Paterson).
[11] Abandoned 1940.
[12] Includes Bob Rose.
[13] Includes North Jacob.
[14] Abandoned 1943; reinstated 1948, includes Jolley.
[15] Abandoned 1941.
[16] Includes South Washburn.
[17] Abandoned 1947.
[18] Gas field abandoned 1948.
[19] Abandoned 1940; reinstated 1949.
[20] Abandoned 1949.

LINE NUMBER	NUMBER OF WELLS[c]			WELLS PRODUCING[f] DEC. 1949			RESERVOIR PRESSURE LB PER SQ INCH		SECONDARY RECOVERY[g]	CHARACTER OF OIL[h]		PRODUCING FORMATION					DEEPEST ZONE TESTED[n] TO END OF 1949	
	COMPLETED TO END 1949	1949		OIL		GAS	INITIAL	AVG./END 1949		GRAVITY A.P.I.	SULPHUR PER CENT	CHARACTER[i]	POROSITY PER CENT[j]	DEPTH TO TOP OF PRODUCING ZONE FT.[k]	PROD. THICKNESS AVG. FT. / NET	STRUCTURE[m]	NAME	DEPTH OF HOLE, FT.
		COMPLETED	ABANDONED	FLOWING	ARTIFICIAL LIFT													
67	668	33	44		504	4	1,500	x		27	0.9	L	P	2,100	50	F	Travis Peak-Schist	7,859
68	1	1			1		x	x		34		Serp	P	982	14	Intn	Serpentine	1,109
69	163		3		133		1,250	x		31.5	0.4	Serp	12	1,535	x	Intn	Edwards ls	2,050
70	3			Abd	- 1942		x	x		34		Serp	P	720	x	Intn	Edwards ls	850
71	1				1		1,250	x		37	0.9	C	Fis	2,260	30	F	Edwards ls	2,800
72	1	1			1		x	x		28		L	P	1,872	9	Intn	Serpentine	1,891
73	1						x	x		Gas		S	P	2,638	7	A	Navarro	2,995
74	437	6	12		415		x	x		38	0.2	S-Sh	P	600	15	T	Edwards ls	5,000
75	3				3		3,250	x		45		L	P	8,993	25	F	Edwards ls	9,060
76	18	1	1		8		x	x		20.7		S	P	1,200	12	M L	Pettus	1,501
77	1			Abd	- 1941		340	x		27	0.8	S L	P	2,570	30	F	Edwards ls	3,342
78	49	21		7	41		x	x		32	0.4	C L	Fis	5,400	x	A F	Edwards ls	6,312
79	38		1	3	29	4	1,500	x		25		S	34	3,890	30	A C	Travis Peak	10,050
							1,997	x		Gas		S	23	4,254	27	A		
80	3						x	x		Gas		S	P	1,084	x	A	Taylor (San Miguel)	3,005
														1,884				
81	8			Abd	- 1940		x	x		23		C	P	1,100	x	F	Austin chalk	1,150
82	1				1		x	x		41.4		L	P	3,562	50	F	Austin chalk	3,612
83	1			Abd	- 1947		x	x		32.8		S	P	3,638	20	F	Midway	6,639
84	1				1		x	x		45		S	P	5,248	5	F	Wilcox	5,253
85	13					10	x	x		Gas		S	P	1,800	12	M F L	Yegua	3,534
86	7				2		x	x		39		C-Serp	P	1,667	x	F	Austin chalk	1,777
87	304	3	5	1	198		x	x		36	0.6	L	P	2,670	25	F	Edwards ls	2,918
88	6					2	2,400	x		Gas		S	P	6,416	37	A F	Wilcox	9,130
							2,500	x		Gas		S	P	6,900	27			
							3,800	x		Gas		S	P	8,250	47			
89	13				7		x	x		23		S	P	1,150	16	M L	Yegua	2,170
90	2	1			2		x	x		35.4		S	P	5,421	4	A	Wilcox	5,425
91	2		1		1		x	x		12		L	P	995	52	F	Edwards ls	1,192
92	915				251		300	x		36	1.4	S-Sh	P	1,200	30	T F	Travis Peak	5,311
93	103				82		x	x		32	0.5	S	16	600	10	F L	Glen Rose	3,850
94	6				4		x	x		38.3		L	P	2,012	x	F	Edwards ls	2,382
95	3	2			3		x	x		30-36		C	F	776	27	F	Edwards ls	1,129
96	17				2		x	x		18.5	0.5	S-Sh	15	290	16	F	Edwards ls	2,048
														940	10	T		
97	25				6		x	x		38		C L	P	2,340	60	F	Buda ls	2,705
98	28	1		9	13		400	x		37		Serp	25	700	75	Intn	Travis Peak	3,290
99	5	1			x		x	x		17		L	P	430	x	x	Glen Rose	690
100	2			Abd	- 1947		x	x		35		C	P	2,582	30	F	Del Rio	2,808
101	1						840	x		Gas		S	P	1,960	5	N	Taylor	2,538
102	112		9		90	1	x	x		34	0.4	S-Sh	10	506	20	F	Edwards ls	2,835
103	8	2	1		2		x	x		36		L-Serp	P	1,230	100	Intn	Austin chalk	1,900
														1,476	14			
104	14				9		x	x		18		L	P	293	10	x	Glen Rose	424
105	26	1			18	1	x	x		42		S	P	4,822	10	F	Edwards ls	11,038
														5,123	17			
														5,532	28			
														6,030	20			
106	39	12		28	10		x	x		24		S	P	3,766	17	F	Midway	6,512
107	3						x	x		Gas		S	P	370	12	M L	Yegua	1,645
108	1	1			1		x	x		44		S	P	2,560	10	A F	Taylor	3,333
109	3	3			3		x	x		38		L	F	2,041	48	F	Edwards ls	2,362
														2,166				
110	7				4		400	x		27		Serp	20	1,335	100	Intn	Edwards ls	2,600
111	14		3	1	8	1	150	x		30.4	0.8	C	Fis	2,050	75	F	Edwards ls	2,600
	5,594	250	112	275	3,293	41												

TABLE 2 - SUMMARY OF DRILLING OPERATIONS IN SOUTH CENTRAL TEXAS

IMPORTANT WILDCATS DRILLED IN 1949

LINE NUMBER	COUNTY	SURVEY	TOTAL DEPTH FT	DEEPEST HORIZON TESTED	WELL NAME	REMARKS
1	Bastrop	M. Baker	1,881	Austin chalk	Jessie I. White, # 1 Martin Mc Donald	Discovery well of Marsha Field, located 8 miles southwest of Bastrop. Initial production 112 bbl oil per day, 28° gravity, 1/4" choke, gas-oil ratio 200:1. Producing from Dale limestone at 1,872-1,881 ft. Completed Aug 5, 1949.
2	Bexar	Fernando Rodriguez	4,425	Schist	Union Producing Co. # 1 L. S. Mc Kean, et al	Dry and abandoned Feb. 2, 1949, located three miles southwest of San Antonio. Top of Schist 4,370 ft. Tested Austin chalk through perforations 1,230-90 ft, recovered small amount of oil.
3	Caldwell	Byrd Lockhart	1,637	Austin chalk	H. V. Muckelroy, # 1 Dave Joseph	Discovery well of Lane Field, located one mile east of Lockhart. Completed March 31, 1949, for initial production of 61 bbl oil per day, pumping, 41° gravity. Producing from Austin chalk 1,603-1,637 ft.
4	Caldwell	S. B. Morrison Lge.	704	Austin chalk	Fred J. Adams, # 1 Mrs. Fred J. Adams	Extended production of old Staples Field of Guadalupe County. Completed Aug. 16, 1949, for initial production of 22.76 bbl oil per day, pumping, 36° gravity, no water. Producing from open hole 671-704 ft, 7" casing set at 671 ft.

TABLE 2 - Continued SUMMARY OF DRILLING OPERATIONS IN SOUTH CENTRAL TEXAS

IMPORTANT WILDCATS DRILLED IN 1949

LINE NUMBER	COUNTY	SURVEY	TOTAL DEPTH FT	DEEPEST HORIZON TESTED	WELL NAME	REMARKS
5	Caldwell	Nancy Heavrill	2,229	Edwards	Magnolia Petroleum Co. # 1 Frank Roberts	Extended production of Luling Field 1,600 ft northwest. Completed June 2, 1949, initial production 74.88 bbl oil per day, 27.5° gravity, 1/4" choke, gas-oil ratio 175:1, 50% water. Tubing pressure 225 lb, casing sealed, 7" casing set at 2,229 ft, perforated 2,200-26-1/2 ft with 57 shots.
6	Dimmit	Mills M. Battles # 11-1/2	3,333	Olmos sand (Navarro)	Continental Oil Co. # 1 Ewell Mc Knight	Discovery well of Wintergarden Field, located three miles southwest of Carrizo Springs. Initial production 24 bbl, 44.3° gravity oil per day, pumping, 6" casing set at 3,333 ft. Perforated from 2,555-69 ft.
7	Edwards	Sec. 87, H. E. & W. T.	7,811	Ellenberger	H. N. Naylor Oil Co. # 1 Lloyd Mitchell	Dry and abandoned March 10, 1949. Located 21 miles northeast of Rock Springs. Reported shows of oil in Strawn and Devonian. Top of Marble Falls 4,707 ft, top of Ellenberger 4,738 ft.
8	Frio	John Bruggeman, # 133	3,280	Olmos sand (Navarro)	Shell Oil Co., # 1-A T. W. Bain	Discovery well of Big Foot Field, located 14 miles northeast of Pearsall. Completed Jan. 1, 1949, for initial production of 8 bbl, 44° gravity oil per day and 8,000 cu ft gas, 7" casing set at 3,211 ft, open hole 3,211-80 ft.
9	Frio	F. Hoyer, # 142	3,299	Olmos sand (Navarro)	Miller Royalty & C. C. Dauchy, # 1 C. B. Thompson	Extended Big Foot Field 1-2/3 miles southeast of discovery well. Completed Feb. 17, 1949 for 20 bbl oil per day, 43.7° gravity, pumping, from open hole 3,282-99 ft, 5-1/2" casing set at 3,282 ft.
10	Frio	N. Nanez, # 1078	6,705	Edwards	M. L. Massingill, # 1 Rex Shuptrine	Discovered Divot Field, located 2 miles east of Doering Field. Initial production from Austin chalk in open hole 5,584-5,980 ft, 188 bbl, 33° gravity oil per day, 3/16" choke, gas-oil ratio 80:1, no water, 5-1/2" casing set at 5,584 ft. Drill stem test at 6,485-6,510 ft, in Edwards limestone, recovered salt water. Completed June 8, 1949.
11	Frio	H. B. B. & C., # 1081	6,507	Edwards	Humble Oil & Ref. Co. # 2 Frank Doering, Acct. 2	Opened new producing horizon and extended Doering Field production 4,500 ft southeast of discovery. Completed June 2, 1949 for 6,000,000 cu ft gas per day, open flow, with spray of condensate. Shut-in pressure 1,642 lb. Top of Navarro sand 4,106 ft, 5-1/2" casing set at 5,068 ft, perforated 4,106-13 ft.
12	Guadalupe	J. W. Williams Lge.	2,105	Austin chalk	H. L. Turner & San Marco # 1 A. G. Bode	Discovered Jayeddie Field, located 8 miles east of Seguin. Completed Aug. 29, 1949, flowing 226 bbl oil per day, 29° gravity, 1/4" choke, 7" casing set at 2,015 ft, producing from open hole 2,015-2,105 ft. Tubing pressure 150 lb, casing pressure 100 lb, no water.
13	Guadalupe	H. Cottle	2,215	Austin chalk	Parker Petroleum Co. # 1 O. Engelke	Discovery well of Wolf Creek Field, located 9 miles southwest of Luling. Completed April 22, 1949, for initial production of 138 bbl, 38° gravity oil per day, pumping, no gas, 49% water. Producing from open hole 2,170-2,215 ft in Buda limestone.
14	Kinney	H. E. & W. T. R. R. # 557	4,750	Pennsylvanian	Phillips Petroleum Co. # 1 Louis (Hobbs Ranch)	Dry and abandoned March 19, 1949. Located 2 miles southwest of Spofford.
15	La Salle	Section 164, H. & G. N.	12,542	Edwards	Plymouth Oil Co., # 1 Archbishop of San Antonio	Abandoned Oct. 21, 1949. Located four miles west of Washburn Field. Tested dry in Edwards limestone at 10,505 ft and dry in Wilcox from 5,426-32 ft. While pulling 5-1/2" casing, well blew out, flowed gas through 4" line, estimated 30,000,000 cu ft from section between 4,294-4,550 ft in Carrizo-Wilcox. Killed and temporarily abandoned.
16	La Salle	Section 164, H. & G. N.	5,651	Wilcox	Plymouth Oil Co., # 2 Archbishop of San Antonio	Dry and abandoned Oct. 29, 1949, located 1,320 ft west of # 1 Archbishop of San Antonio. Cored and tested salt water in section from which # 1 blew out.
17	Mc Mullen	J. M. Hernandez, # 134	5,791	Wilcox	Rowan & Hope & M. L. Massingill, # 1 H. M. Hoark	Discovery well of Green Franklin Field, located eight miles north of Tilden. Initial production 61 bbl, 38° gravity oil per day, 1/8" choke, tubing pressure 675 lb, casing sealed, gas-oil ratio 627:1, 7" casing set at 5,109 ft, perforated 5,090-5,110 ft with 72 shots. Completed Sept. 12, 1949.
18	Mc Mullen	T. H. Wilson, # 104	9,502	Wilcox	Sunray Oil Corp., # 1 Gorman-State	Dry and abandoned July 21, 1949. Located in South Campana Field. Top of Queen City 5,990 ft. Tested Queen City and Wilcox.
19	Mc Mullen	G. B. Kinney, # 481	6,920	Wilcox	Delhi Oil Corp., # 3 Hagist Ranch, Inc.	Extended Loma Alto-Wilcox Field 6,300 ft southwest. Completed Dec. 20, 1949, for initial production of 11,000,000 cu ft gas per day open flow, shut-in pressure 2,600 lb, gas-oil ratio 71,430:1, 5-1/2" casing set at 6,918 ft, perforated 6,846-1/2 to 6,861 ft. Top of first Wilcox 6,833 ft.
20	Medina	A. B. & M., # 47	7,168	Schist	Humble Oil & Ref. Co. # 1 E. E. Wilson	Completed Jan. 12, 1949 as water well at 2,100 ft after running electrical log to 7,168 ft and taking side wall cores, no shows. Top of Schist 6,970 ft.
21	Medina	# 449-3/4	3,056	Houston	Harry W. Mc Cormick # 1 James Anderson	Dry and abandoned Aug. 28, 1949. Projected as a pre-Cretaceous test, lost hole in lower Cretaceous.
22	Travis	Pedro Rodriguez	1,009	Serpentine	Anderson-Prichard, # 1 G. E. Johnson	Discovery well of Lund Field, located 6 miles northwest of Elgin. Completed March 19, 1949, pumping 11.62 bbl oil per day, 34° gravity, no water, from open hole 982-996 ft. Top of Serpentine 987 ft, plugged back total depth 996 ft, 5-1/2" casing set at 982 ft.
23	Uvalde	H. E. & W. T., Ab-1116	6,503	Pennsylvanian	The Texas Co., # 1 C. C. Mitchell, et al	Dry and abandoned Jan. 19, 1949. Located 3.8 miles southwest of Utopia, in extreme northeast corner of county. No shows of oil or gas reported.
24	Williamson	H. E. Booth	1,138	Serpentine	Anderson-Prichard, # 1 Charlie Preusse	Discovery well of Southwest Byersville Field, located six miles southeast of Taylor. Completed June 12, 1949, for initial production of 147.05 bbl, 38.4° gravity oil per day, pumping, no water, 5-1/2" casing set at 1,109 ft, producing from Dale limestone, open hole, 1,109-1,137 ft.

	IN PROVEN FIELDS	WILDCATS
Number of wells drilling Dec. 31, 1949	20	26
Number of oil wells completed during 1949	231	11
Number of gas wells completed during 1949	7	0
Number of dry holes completed during 1949	76	227

Oil And Gas Developments In Kentucky During 1949

By COLEMAN D. HUNTER,* ILEY BROWNING, JR.,** WALTER SCOTT BROWNING,† and WOODSON DIAMOND ‡

During 1949 in Kentucky, 1,115 wells were drilled, 460 of which were oil producers, 196 were gas producers, and 459 were dry holes. The total oil production for the state was 8,806,230 bbl, 118,061 bbl less than produced during 1948.

Western Kentucky showed a decrease of 28,000 bbl during the year, but new discoveries and development in Union County during September, which increased production by the end of December to over 100,000 bbl monthly, indicate that 1950 will be a better year.

Oil production in Eastern Kentucky was increased 43,919 bbl due to a 30,000 bbl increase in the new Wolfe County extensions of the old Big Sinking oil fields and also due to repressuring in the Weir sand oil fields of Johnson, Lawrence, and Magoffin Counties.

South Central Kentucky showed a marked decline of 134,000 bbl because of a 174,000 bbl decline in the short-lived flashy Stones River production in Clinton County, and there were no new discoveries of this nature. Extensions of old oil fields in Allen, Cumberland, and Wayne Counties, and new development in Russell County, are responsible for the 40,000 bbl increase in these counties.

The only new oil development of importance in Eastern Kentucky, during the past five years, was in the new White Creek field of Wolfe and Powell Counties. This development is more of an extension of the Big Sinking field which has been retarded due to property litigation rather than a discovery. The first wells were drilled in 1948. During 1949, the additional 27 oil wells drilled, producing from the Corniferous, are responsible for increasing Wolfe County's annual production from 19,000 bbl in 1948 to 50,000 bbl in 1949, and Powell County's 1948 production of 62,000 bbl to 66,000 bbl in 1949.

During the year, two deep Knox tests were drilled. The first, drilled on Wallace Williams' farm by Ashland Oil & Refining Co., is located high on the Paint Creek uplift on the Laurel Creek dome in Johnson County. This well was drilled to a total depth of 5,110 ft. The Knox Dolomite, which was from 4,870 ft to 5,110 ft, had two sand zones, from 4,968 ft to 4,105 ft and from 5,095 ft to 5,110 ft. Gas shows were encountered at 5,097 ft to 5,100 ft, and oil shows from 5,365 ft to 5,370 ft and from 5,528 ft to 5,532 ft. At 5,684 ft, both water and oil were encountered. The well was pulled, plugged, and abandoned.

Another test, by Arch Carpenter, on a farm-out from the California Co., was drilled in Carter County to a depth of 3,840 ft. A good show of oil was encountered in the St. Peter sand from 3,595 ft to 3,606 ft and was drilled on into the Knox where Blue Lick water was encountered at 3,836 ft. The hole was plugged back to the St. Peter and the well was shot. After shot several bbl of oil were bailed and the well was pulled, plugged, and abandoned.

The most important gas development was in South East Kentucky in the Big Sandy gas field. During the year, 186 wells were drilled, 149 of which were gas producers de-

TABLE I - SUMMARY OF WELLS DRILLED IN KENTUCKY AND OIL PRODUCED DURING 1949 AS COMPARED TO 1948

AREA	NO. WELLS DRILLED		OIL		GAS		DRY		OIL PRODUCTION	
	1948	1949	1948	1949	1948	1949	1948	1949	1948	1949
Western Kentucky	574	673	253	364	7	9	314	300	7,084,934	7,056,662
Eastern Kentucky	330	316	51	54	182	183	97	79	1,310,512	1,354,430
South Central Kentucky	152	126	90	42	6	4	56	80	528,845	395,138
Total Kentucky	1,056	1,115	394	460	195	196	467	459	8,924,291	8,806,230

EASTERN KENTUCKY

Eastern Kentucky, during 1949, experienced development comparable with 1948. During the year, 316 wells were

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veloping a total open flow of 101,950 Mcf. There were no new gas fields discovered during 1949, and all gas in the field was either inside or extension development. (See Table 2).

mate gas recovered in Eastern Kentucky.

In the old Corniferous Artemus-Himyar field of Knox County, 11 wells were drilled as inside or extension

TABLE 2 - DEVELOPMENT IN BIG SANDY GAS FIELD DURING 1949 AS COMPARED TO 1948

COUNTY	PRODUCING GAS WELLS		PRODUCING OIL WELLS		DRY HOLES		TOTAL WELLS DRILLED		OPEN FLOW DEVELOPED		PRODUCING FORMATIONS ORDER OF IMPORTANCE
	1948	1949	1948	1949	1948	1949	1948	1949	1948	1949	
Knott	27	25	0	1	4	3	31	29	4,481	5,411	Black Shale (Dev.), Big Lime (Miss.) Maxon (Miss.), Salt Sand (Penn.)
Martin	9	6	2	0	5	2	16	8	3,374	4,257	Black Shale (Dev.), Salt Sand (Penn.) Maxon (Miss.)
Floyd	12	14	0	0	6	5	18	19	3,206	6,341	Black Shale (Dev.), Maxon (Miss.), Big Lime (Miss.), Salt Sand (Penn.)
Johnson	10	3	0	0	2	3	12	6	4,005	254	Weir (Miss.), Big 6 (Sil.), Black Shale (Dev.)
Magoffin	36	14	1	0	20	11	57	25	180,329	25,882	Big 6 (Sil.), Weir (Miss.), Salt Sand (Penn.), Maxon (Miss.), Black Shale (Dev.)
Pike	71	87	0	2	15	10	86	99	48,205	59,809	Black Shale (Dev.), Maxon (Miss.), Big Lime (Miss.), Salt Sand (Penn.), Weir and Berea (Miss.)
Total	165	149	3	3	52	34	220	186	243,600	101,954	

At the end of 1949, in the Big Sandy field, 4,649 wells had been drilled, 2,742 of which produced from the Devonian Shale. Statistics of results obtained from shooting from 500 to 600 ft of Black Shale, with 6,000 lb or more of gelatinated nitroglycerin, are of interest.

Of 2,742 shale producing wells drilled, only 4.8 per cent are natural producers which do not require shooting, 38.5 per cent have no open flow before shot, and 83.8 per cent have less than 100 Mcf before shot. The percentage of dry holes, after shot, is 9.2 per cent and the average open flow for all shale wells is 327 Mcf per well. Although the average shale well open flow is much smaller than the average producing gas well from the more shallow Pennsylvanian and Mississippian formations above, and the deeper Devonian and Silurian sands and Dolomites below, the life of the well is much longer and the Devonian Shales are responsible for over 70 per cent of the ulti-

wells, developing a total open flow of 17,597 Mcf. No dry holes were drilled.

Six St. Peter producing wells, drilled in the old Furnace oil field during 1949, developed a total open flow of 22,388 Mcf. This gas production, which is high in CO_2 and has a very low Btu content, has not to date been marketed.

In Powell County, eight very small gas wells of only local importance were drilled, producing from the Corniferous at depths of 350 ft.

In the old depleted Turkey Knob Corniferous gas field of Owsley County, a dry hole was drilled in testing the Knox Dolomite before completely abandoning the field. (See Tables 3 and 4, and Map.)

TABLE 3 - DEVELOPMENT AND PRODUCTION IN EASTERN KENTUCKY DURING 1949 AS COMPARED WITH 1948

COUNTY	NO. WELLS DRILLED		PRODUCING OIL		PRODUCING GAS		DRY		OIL PRODUCED	
	1948	1949	1948	1949	1948	1949	1948	1949	1948	1949
Bath	1	1	0	0	0	0	1	1	11,099	9,893
Boyd	3	3	0	0	0	3	3	0	376	263
Breathitt	2	11	0	4	1	3	1	4	0	465
Carter	2	5	0	0	0	0	2	5	0	0
Clay	2	0	0	0	1	0	1	0	0	0
Clark	1	0	0	0	0	0	1	0	0	0
Elliott	2	2	2	1	0	0	0	1	16,727	18,567
Estill	17	6	12	0	2	6	3	0	202,017	196,472
Floyd	18	19	0	0	12	14	6	5	17,774	11,093
Fleming	1	0	0	0	0	0	1	0	0	0
Greenup	0	1	0	0	0	0	0	1	0	0
Jackson	8	5	6	3	0	0	2	2	32,635	21,286
Johnson	12	6	0	0	10	3	2	3	196,069	248,990
Knott	31	29	0	1	27	25	4	3	2,885	3,649
Knox	15	12	0	0	14	11	1	1	0	0
Laurel	0	0	0	0	0	0	0	0	829	0
Lawrence	0	7	0	1	0	2	0	4	143,412	146,559
Lee	4	6	0	3	0	0	4	3	348,261	328,081
Magoffin	57	25	1	0	36	14	20	11	189,657	190,339
Martin	16	8	2	0	9	6	5	2	43,693	41,146
Madison	0	8	0	4	0	0	0	4	0	150
Menifee	24	3	16	0	0	1	8	2	17,886	11,984
Morgan	2	1	0	0	0	1	2	0	1,191	934
Owsley	1	4	0	0	0	0	1	4	2,734	2,646
Powell	30	21	12	8	6	7	12	6	62,567	66,496
Pike	86	99	0	2	71	87	15	10	1,224	5,184
Rowan	1	2	0	0	0	0	1	2	0	0
Wolfe	2	32	0	27	0	0	2	5	19,475	50,233
Total	338	316	51	54	189	183	98	79	1,310,511	1,354,430

TABLE 4 - MONTHLY OIL PRODUCTION IN KENTUCKY DURING 1949 BY COUNTIES*

COUNTY	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	TOTAL
Allen	4,047.43	4,322.23	5,115.24	4,901.69	5,262.16	5,786.72	6,276.76	5,397.85	6,424.46	6,681.47	6,798.48	6,667.31	67,681.80
Barren	201.72	728.04	638.00	1,001.61	839.74	716.00	1,003.38	826.06	792.64	1,007.12	784.50	856.40	9,395.21
Bath	837.36	862.03	1,032.48	790.52	932.37	935.94	703.22	953.30	667.85	882.79	794.27	500.60	9,892.73
Boyd		62.56			60.95	69.62			69.70				262.83
Breathitt						148.69			157.48			158.88	465.05
Breckenridge	235.42	79.73	369.89	237.27	210.61	158.52	286.91	236.23	159.09	212.25	292.27	293.65	2,771.84
Butler	8,216.43	8,497.82	8,165.05	8,712.09	8,385.62	8,440.35	8,868.94	8,200.14	9,245.40	8,082.80	7,896.59	8,329.76	101,040.99
Clinton	25,669.10	21,835.41	23,685.73	22,226.76	24,296.79	18,501.82	22,009.02	21,441.59	18,553.40	19,689.09	17,719.81	16,401.23	252,029.75
Crittenden	69.78		71.80		87.70		79.87	58.39	166.05		179.49	90.53	803.61
Cumberland	1,939.98	1,685.94	2,213.55	1,838.26	2,245.72	3,453.94	2,637.74	3,437.65	3,436.19	3,393.71	3,226.76	3,136.29	32,645.73
Daviess	106,066.43	105,076.56	114,172.79	110,361.92	111,677.07	105,285.55	114,229.61	117,824.32	133,352.62	129,924.28	122,298.11	122,256.76	1,392,526.02
Edmondson		68.87					70.43			130.45			269.75
Elliott	1,943.94	1,229.83	1,847.37	1,626.82	1,649.67	1,491.76	1,515.25	1,633.20	1,331.02	1,384.28	1,520.15	1,393.28	18,566.57
Estill	18,294.22	14,710.52	17,918.76	16,051.29	16,592.17	16,882.82	14,428.50	17,400.81	16,678.84	16,925.50	15,462.07	15,124.81	196,472.31
Floyd	331.25	794.42	995.86	878.46	1,503.55	1,267.21	880.57	977.76	576.34	461.41	1,252.83	1,173.70	11,093.36
Hancock	6,649.79	5,682.83	7,569.91	6,511.67	6,764.52	5,742.27	6,440.87	6,921.73	6,716.82	6,672.77	6,201.39	6,599.11	78,473.68
Hart	1,292.86	1,753.54	1,758.55	1,047.39	1,497.26	873.50	1,682.53	2,539.21	1,146.05	1,822.97	1,331.63	2,280.87	19,026.36
Henderson	156,690.96	140,829.46	161,325.43	152,975.14	158,077.58	149,435.31	155,502.05	138,295.48	147,772.23	153,853.26	141,853.66	144,637.38	1,801,247.94
Hopkins	569.13	561.05	383.59	187.68	377.25	349.36	544.59	376.15	182.31	381.27	186.86	191.76	4,291.00
Jackson	2,637.34	1,951.04	2,293.21	1,985.01	1,888.25	1,667.45	1,685.53	1,472.90	1,461.77	1,171.73	1,320.60	1,751.39	21,286.22
Johnson	17,354.20	16,881.68	20,578.67	23,089.21	22,605.90	24,716.76	17,472.40	20,249.84	24,104.19	17,795.61	21,762.07	22,379.67	248,990.20
Knott	207.90	347.01	314.32	485.46	368.62	417.51	261.30	310.92	279.03	186.97	232.13	237.69	3,648.86
Lawrence	10,828.03	10,788.74	11,010.63	12,627.63	12,079.80	12,160.84	13,127.34	15,861.85	8,976.82	15,309.48	11,953.47	11,834.07	146,558.70
Lee	27,218.18	26,177.29	30,015.60	22,717.75	27,898.38	29,023.70	27,905.83	28,688.17	26,584.24	27,757.82	26,778.81	27,314.93	328,080.70
Logan	951.36	968.50	852.00	842.00	970.65	1,157.67	521.46	1,035.56	1,334.80	1,407.93	1,260.01	1,237.18	12,539.12
Madison								150.00					150.00
Magoffin	15,697.04	15,011.60	17,690.40	15,360.91	16,246.36	15,856.85	14,554.25	17,264.89	15,411.89	16,094.49	15,658.05	15,492.73	190,339.46
Martin	3,953.74	2,919.53	3,748.05	3,641.78	2,970.07	3,571.62	3,129.28	3,371.08	3,363.67	3,334.26	3,528.52	3,614.65	41,146.25
Mc Creary	71.15	140.68	71.93	156.98	84.84	70.05	76.61					55.85	708.09
Mc Lean	58,643.79	56,412.85	61,735.63	57,433.92	59,788.42	48,277.34	54,651.72	47,215.60	61,135.94	62,311.63	62,464.38	59,612.25	689,683.47
Meade		122.13	40.71			162.86		81.43		81.43		40.71	529.27
Menifee	1,279.26	1,025.28	975.05	1,099.26	1,484.47	1,114.19	853.02	1,096.64	841.94	869.55	772.96	572.08	11,983.70
Metcalfe	68.87	68.87	68.87		68.87		70.48		70.62		71.85		488.43
Monroe							93.00	70.07					163.07
Morgan	237.52			90.29	86.92	88.16	84.95		163.74	85.47		97.20	934.25
Muhlenberg	700.12	966.48	1,273.70	1,201.81	1,928.39	2,018.87	2,755.55	2,374.17	2,312.55	2,296.08	2,526.01	1,817.04	22,170.77
Ohio	30,686.21	29,214.31	34,767.05	31,477.10	30,427.89	27,655.94	33,523.02	33,322.09	38,653.86	38,085.04	33,721.09	35,277.25	396,810.85
Owsley	147.83	106.79	321.08	94.83	268.28	124.01	111.45	366.30	237.76	363.45	349.16	155.05	2,645.79
Pike	524.43	421.44	332.24	289.24	395.28	329.34	272.74	396.25	428.78	330.55	874.08	589.93	5,184.30
Powell	5,555.91	6,774.49	5,451.17	5,362.95	5,410.73	5,299.97	5,026.49	5,904.05	5,876.01	4,790.95	6,098.80	4,944.47	66,495.99
Russell		2,660.01	134.44	1,997.57	133.20	62.71	62.15	86.76		50.12		269.61	5,456.57
Simpson	118.35	116.94		89.96	65.00	114.56	45.00	20.00	70.50	71.18		161.90	853.39
Todd							110.00		110.00				220.00
Union	162,998.52	125,323.57	168,646.51	156,117.14	171,088.04	158,039.40	162,615.99	142,209.69	177,102.75	198,811.03	270,192.23	270,612.47	2,163,777.34
Warren	3,637.74	2,767.18	4,712.36	3,504.08	3,761.64	3,764.72	4,302.28	3,528.98	4,144.20	3,192.21	3,173.17	4,325.71	44,814.27
Wayne	2,226.13	1,623.65	2,276.60	2,089.87	1,947.63	3,069.03	2,139.47	1,953.22	2,207.69	2,053.48	2,249.52	2,530.81	26,367.10
Webster	29,463.22	28,410.30	31,293.17	24,682.23	27,394.86	19,776.51	33,447.02	25,610.12	28,090.43	27,483.56	26,001.96	23,361.71	325,015.09
Wolfe	2,962.81	1,423.15	3,398.27	2,925.09	3,977.54	3,978.24	3,425.46	3,872.12	4,232.04	5,479.12	6,487.06	8,071.96	50,232.86
Total	711,225.25	641,404.35	749,265.66	698,692.64	733,780.76	682,077.68	719,484.03	683,032.57	754,623.71	780,918.56	825,274.80	826,450.63	8,806,230.64

*Note - Production to hundreth of bbl

MAP
OF
OIL & GAS FIELDS
OF
EASTERN KENTUCKY

SCALE - 1 INCH = 8 MILES

WESTERN KENTUCKY

Western Kentucky oil development activity during the first part of 1949 was rather slow; but, by the end of 1949, 673 wells were drilled, of which 364 produced oil, 9 produced gas, and 300 were dry holes. (See Table 5). While the total number of wells drilled for the year, both in proven fields and wildcats, was greater than in 1948, most of the activity came in the latter part of the year during November and December, when the number of wells being drilled in the whole Illinois Basin increased greatly, Wildcats increased from 92 in 1948 to 117 in 1949, of which 21 produced oil and 1 produced gas. (See Table 6). Many of the discoveries and pool extensions came in this late increase in activity and as a result did not have time to greatly influence total yearly production for the area. (See Tables 7 and 8). Union County, which was a center of development, increased from 142,000 bbl in August to 270,000 bbl in December. Normal decline of proven production offset the late increase with the result that total Western Kentucky production for 1949 was less than 1948. However, the aforementioned new discoveries and pool extensions, with a continuation of the favorable business and price conditions evident in the area in the latter part of 1949, promise an increase in both drilling activity and production for 1950.

Pennsylvanian. Waltersburg, Hardinsburg and Cypress Sandstones, and the Mc Closky Limestone, with the biggest producer being the Waltersburg sand.

Further development was carried on in the Griffith Pool of Daviess County. The Waltersburg and Tar Springs Sandstones have been productive at depths of 1,100-1,200 ft, and at the close of December the pool contained 131 wells with a daily average run of 928 bbl.

In November, an important extension of the Poole Consolidated Field of Henderson-Webster Counties was brought in by Iley B. Browning, Sr., on the Osborn Heirs farm, slightly less than a mile south of present production. Pay zones are the Palestine and Hardinsburg Sandstone with good shows in the Waltersburg and Tar Springs. At the end of December, there were two wells on the block which give promise of substantial expansions for the Poole Consolidated field.

Deeper drilling was limited in Western Kentucky during 1949, which saw the abandonment of the interesting Knox Dolomite test in Webster County on the Sebree anticline. The well was abandoned at 6,886 ft after penetrating only a few hundred feet of the Knox when drilling progress became slow. Two shows of oil had been found, one in the

TABLE 5 - DEVELOPMENT AND PRODUCTION IN WESTERN KENTUCKY DURING 1949 AS COMPARED WITH 1948

COUNTY	NO. WELLS DRILLED		PRODUCING OIL		PRODUCING GAS		D R Y		OIL PRODUCED	
	1948	1949	1948	1949	1948	1949	1948	1949	1948	1949
Breckenridge	6	0	2	0	1	0	3	0	1,885	2,772
Butler	17	6	7	4	0	0	10	2	122,396	101,041
Caldwell	4	0	0	0	0	0	4	0	377	0
Crittenden	0	1	0	0	0	0	0	1	0	804
Daviess	154	267	70	169	2	6	76	92	902,055	1,392,526
Grayson	0	4	0	0	0	0	0	4	0	0
Hancock	11	22	1	8	0	1	10	14	81,369	78,474
Hart	2	9	0	4	0	0	2	5	23,266	19,026
Henderson	70	56	29	20	0	0	41	36	2,272,435	1,801,248
Hopkins	14	2	0	0	2	0	12	2	9,131	4,291
Livingston	0	1	0	0	0	0	0	1	0	0
Logan	12	0	2	0	0	0	10	0	16,047	12,539
Meade	6	0	4	0	0	0	2	0	621	529
Metcalfe	0	0	0	0	0	0	0	0	293	488
Mc Lean	79	52	47	31	0	0	32	21	695,057	609,683
Muhlenburg	14	0	3	0	0	0	11	0	9,435	22,171
Ohio	81	100	26	43	0	1	35	56	424,771	396,811
Webster	30	14	13	2	2	1	15	11	457,136	325,015
Union	63	89	40	54	0	0	23	35	2,025,537	2,163,777
Warren	4	1	1	0	0	0	3	1	43,084	44,814
Unclassified	4	48	0	29	0	0	4	19		653
Total	571	673	245	364	7	9	293	300	7,084,895	7,056,662

Daily average production for the Western Kentucky district was approximately 17,000 bbl at the end of December as compared to 15,000 for December, 1948. Most of this increase, however, can be attributed to the two major pool developments in Union County during the year. These were the Caney Mound East Pool and the Morganfield South Pool. The first wells in Caney Mound East were completed during September and by the end of December the daily average production was approximately 2,600 bbl. (See Table 8). Later wells, to be completed in January, will increase this figure greatly as several large producers were brought in. The Delta Drilling Co. No. 3, Walker Estate well, was completed for 2,994 bbl per day initial and several others were nearly as good. The pay zone is the Lower O'Hara, with between 12-22 ft of extremely porous oolitic limestone.

Morganfield South was averaging 1,832 bbl per day at the close of December with many of its 52 wells not being produced at their maximum rate. This pool is directly against the north side of the Rough Creek Fault with several wells actually cutting the fault. Initial production has varied from 10 to 600 bbl per day from the

TABLE 6 - WESTERN KENTUCKY PROVEN AND EXPLORATORY DEVELOPMENT DURING 1949

COUNTY	WILDCATS			PROVEN FIELDS			TOTAL		
	OIL	GAS	D & A	OIL	GAS	D & A	OIL	GAS	D & A
Butler	0	0	2	4	0	0	4	0	2
Crittenden	0	0	0	0	0	1	0	0	1
Daviess	6	0	33	163	6	59	169	6	92
Grayson	0	0	4	0	0	0	0	0	4
Hancock	0	0	7	4	1	7	4	1	14
Henderson	4	0	15	14	0	21	18	0	36
Hopkins	0	0	2	0	0	0	0	0	2
Livingston	0	0	1	0	0	0	0	0	1
Mc Lean	1	0	5	31	0	16	32	0	21
Ohio	3	1	6	41	0	50	44	1	56
Union	6	0	15	48	0	20	54	0	35
Webster	1	0	5	2	1	6	3	1	11
Unclassified	0	0	0	26	0	19	26	0	19
Total	21	1	95	333	8	199	354	9	294

Middle Ordovician (Lexington or Tyrone) and one in the St. Peter Sandstone, but neither were commercially productive.

Twenty-four wells were drilled in Clinton County during the year, only six of which were oil producers. Of the six producers, two are of importance because production is reported as coming from the top of the Knox Dolomite. Branham No. 2, drilled on the north edge of the 76 Pool to a depth of 1,786 ft, came in making 210 bbl per day and is still pumping 100 bbl per day. Of the four offsets drilled to Branham No. 2, all were dry except one which produces 12 bbl per day after being acidized.

If the correlations of Knox as reported are correct and Branham No. 2 is producing from the top of the Knox Dolomite, this well has made more oil than recovered from 75 or more Knox wells drilled in Kentucky which have cost major and private operators millions of dollars in the

TABLE 7 - WESTERN KENTUCKY EXTENSIONS*

DATE	POOL NAME	OPERATOR	FARM	COUNTY	LOCATION	PRODUCING FORMATION	TOTAL DEPTH	I P OIL/WATER
1/26/49	Guffie	Kaufman, et al	# 2 Edwards	Mc Lean	23-N-27			38/0
4/14/49	Buford	Hobbs, et al	# 1 Beagan	Ohio	14-M-31	Benoist	1,093	3/0
5/ 5/49	Glenville	Sohio	# 1 Sourbier, et al	Daviess	19-N-28	Mc Closky	2,014	214/0
5/26/49	Spring Grove	Sun Oil	# 1 Robertson	Union	22-O-18	St. Louis	2,750	28/0
6/30/49	Morganfield, South	Basin Drlg., et al	# 1 Young	Union	20-O-19	Waltersburg	1,900	88/6
8/11/49	Caney Mound	Ryan Oil, et al	# 1 Greathouse	Union	24-Q-20	Cypress	2,526	132/0
8/11/49	Glenville	Wasson Oil	# 1 Goodwin	Daviess	17-N-28			118/0
9/ 8/49	Utley North	Hartman	# 4 Culver Hrs	Union	11-P-20	Mc Closky	2,677	55/14
9/22/49	Wabash Island	Hartman, et al	# 1 Meredith	Union	11-P-18	Mc Closky	2,796	30/0
9/29/49	Waitman	Mc Intosh, et al	# 1 Kelly	Daviess	7-Q-31	Benoist	1,143	12/0
10/27/49	Griffith	Voil, Muth & Sturgeon	# 1 Kurz	Daviess	9-P-28	Waltersburg	1,119	28/0
11/10/49	Waitman	Skiles	# 1 Fullenwelder	Daviess	7-Q-31	Benoist	1,095	24/0
11/12/49	Poole	Iley B. Browning	# 1 Osborn Hrs	Webster	13-N-23	Palestine & Hardinsburg	2,020	68/0

*By courtesy of Herbert Hoffman

TABLE 8 - WESTERN KENTUCKY DISCOVERIES*

DATE	POOL NAME	OPERATOR	FARM	COUNTY	LOCATION	PRODUCING FORMATION	TOTAL DEPTH	I P OIL/WATER	CUMULATIVE PRODUCTION
1/ 6/49	Curdsville, W.	Sohio & Chester	# 1 Shiver Hrs.	Henderson	1-O-26	Benoist	1,829	65/70/24 hrs	469
2/23/49	Waitman	C. E. Skiles	# 1 R. F. Kelly	Daviess	8-Q-31	Mc Closky	1,317	60/24 hrs	31,818
3/ 4/49	Rangers Landing	Sun	# 1 Roy E. Duncan	Henderson	23-O-25		1,986	3 ½/2 ½/24 hrs	1,647
5/ 3/49	Davidson, E.	W. E. Adams, et al	# 1 H. Carden	Ohio	10-M-34	Jackson	425	Est. 1,000,000 ft	
7/30/49	Caney Mound, E.	Delta Drlg., et al	# 1 John Wallier Est.	Union	13-P-20	Lower O'Hara	2,526	Flow 370/24 hrs	215,269
9/15/49	Diamond Island	Nash Refining	# 1 Bower Bros. Walker	Henderson	15-Q-22	Rosiclaire	1,971	134/est/24 hrs	1,994
10/25/49	West Louisville	C. E. Skiles, J. C. Ellis	# 1 R. D. Payne Hrs	Daviess	18-O-27	Tar Springs	1,368	2/3/24 hrs	2,585
10/27/49	Reed, East	Kingwood Oil	# 1 D. Leach	Henderson	15-O-27	Waltersburg	1,195	108/34/24 hrs	5,204
10/27/49	North Creek	S. W. Birdwell	# 1 C. Tichenor	Ohio	7-L-31	Mc Closky & St. Louis	1,550	10/24 hrs	

*By courtesy of Herbert Hoffman

The Miller-Shiarella-Ashland No. 5 Paris well, in the Glenville pool, was made a deep test after losing approximately four hundred feet of section by a fault. At last report the well had swab-tested 20 bbl oil and 60 bbl water in 20 hours at a depth of 3,794-3,812 ft in what is believed to be the Devonian.

A deep test in Ballard County, Township G-5, was drilling below 3,700 ft at the close of December in the top of the Knox Dolomite; and a well by Carter Oil Co. on the Hitesville high, 24-P-21, was dry and abandoned at 4,812 ft in the Devonian Clear Creek chert.

As yet, the deeper formations in Western Kentucky neither have been proved nor disproved and much more drilling will be necessary in order to form definite conclusions regarding their productivity.

SOUTH CENTRAL KENTUCKY

The greatest decline in oil produced during 1949, in comparison to prior years, was in South Central Kentucky. Although 126 wells were drilled, only 40 produced oil, four were small gas wells, and 80 were dry holes. Of the 40 oil wells drilled, 18 were in Allen County and 12 were in Cumberland County as old field extensions, and increased the production 15,000 bbl in Allen and 21,000 bbl in Cumberland over 1948 production.

Because of the rapid depletion from the Stones River production, especially in the 76 Pool, Clinton County only produced 252,000 bbl of oil during 1949 as compared to 431,000 bbl produced in 1948.

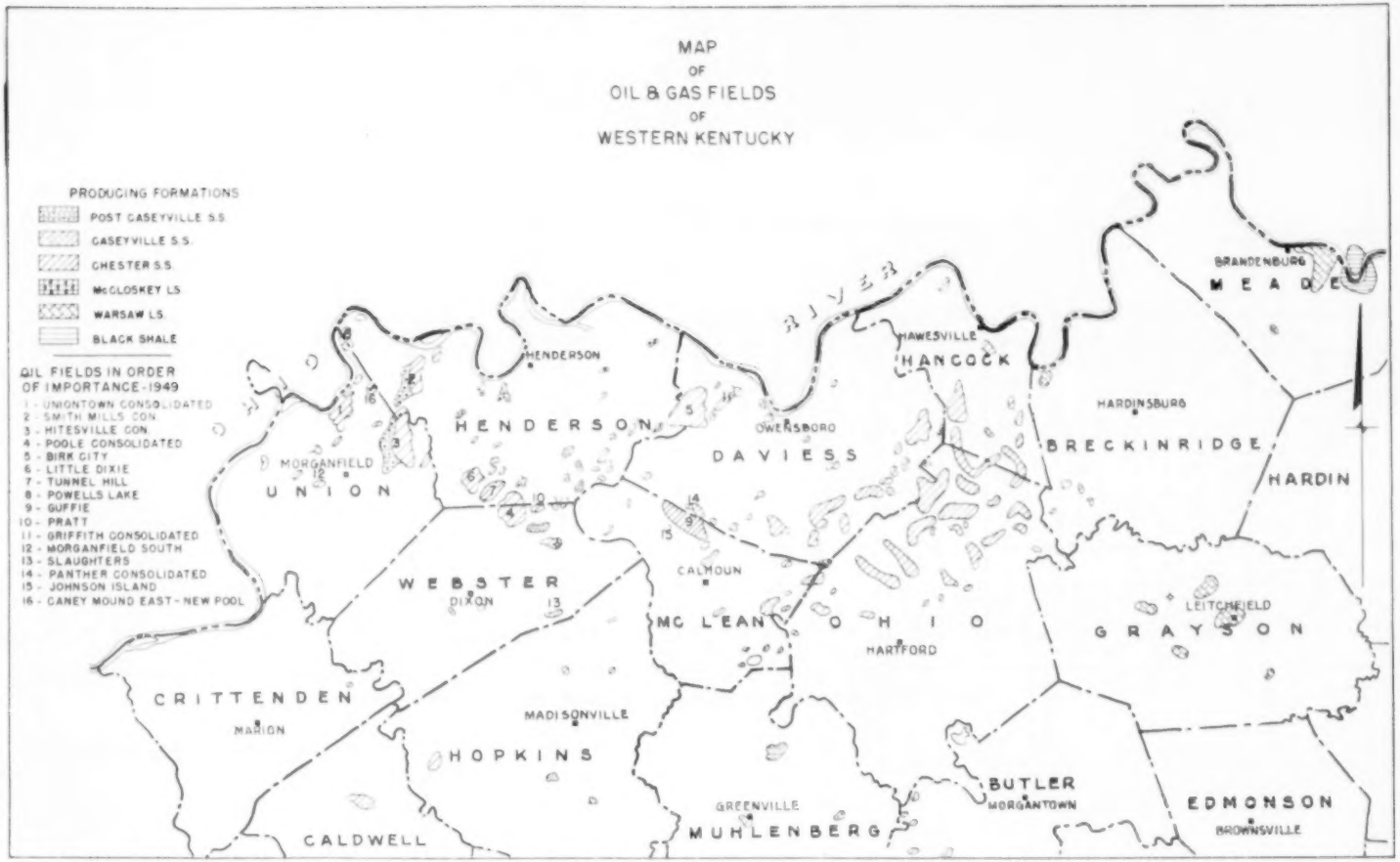
RANK OF WESTERN KENTUCKY POOLS

(CUMULATIVE PRODUCTION DEC. 31, 1949)

POOL	DAILY AVERAGE P. L. RUNS	CUMULATIVE PRODUCTION
Uniontown Consol.	2,109	11,088,353
Smith Mills Consol.	1,307	9,300,222
Hitesville Consol.	1,415	5,317,092
Poole Consol.	946	4,447,463
Birk City	618	3,402,649
Dixie	775	2,423,626
Tunnel Hill	610	1,060,878
Powells Lake	382	1,011,546
Guffie	892	895,356
Pratt	149	549,391
Griffith	928	527,804
Morganfield, South	1,832	456,354
Slaughters	166	426,136
Panther	74	402,549
Johnson Island	319	375,032

TABLE 9 - WESTERN KENTUCKY DRILLING OPERATIONS DURING 1949

| COUNTY | WELLS DRILLED | | | | FORMATION DRILLED - PRODUCTIVE OR DRY | | | |


MAP
OF
OIL & GAS FIELDS
OF
WESTERN KENTUCKY
PRODUCING FORMATIONS
POST CASEYVILLE S.S.
CASEYVILLE S.S.
CHESTER S.S.
McCLOSKEY LS.
WARSAW LS.
BLACK SHALE
OIL FIELDS IN ORDER OF IMPORTANCE-1949
1 - UNIONTOWN CONSOLIDATED
2 - SMITH MILLS CON.
3 - HITESVILLE CON.
4 - POOLE CONSOLIDATED
5 - BIRK CITY
6 - LITTLE DIXIE
7 - TUNNEL HILL
8 - POWELLS LAKE
9 - GUFFIE
10 - PRATT
11 - GRIFFITH CONSOLIDATED
12 - MORGANFIELD SOUTH
13 - SLAUGHTERS
14 - PANTHER CONSOLIDATED
15 - JOHNSON ISLAND
16 - CANEY MOUND EAST - NEW POOL
HENDERSON
HENDERSON
UNION
MORGANFIELD
OWENSBORO
DAVIESS
HAWESVILLE
HANCOCK
BRANDENBURG
MEADE
HARDINSBURG
BRECKINRIDGE
HARDIN
WEBSTER
DIXON
CALHOUN
MC LEAN
OHIO
HARTFORD
LEITCHFIELD
GRAYSON
CRITTENDEN
MARION
MADISONVILLE
HOPKINS
CALDWELL
GREENVILLE
MUHLENBERG
BUTLER
MORGANTOWN
EDMONSON
BROWNSVILLE

past ten years all over Kentucky in exploration for Cambro-Ordovician production.

In Adair County, on the Gradyville Dome, seven wildcat wells were drilled by Woodson Diamond, et al., during 1949. Three of the tests were drilled through the Corder and Corniferous at depths of 350 to 400 ft. Two were drilled through the first and second Sunnybrooks to depths of from 650 to 700 ft. One test was drilled 1,204 ft into the Knox where a hole full of water was encountered. In all the first six wells drilled good oil shows were encountered in the Corder sand above the Black Shale at depths of less than 300 ft. The seventh well drilled on Baker produced from the Corder 25 bbl per day after acidizing, and has produced over 400 bbl of oil. Three offsets are now being drilled and two of the first six drilled, not plugged, will be acidized in both Corder and Corniferous where good shows of oil were encountered.

In Wayne County, where only eight of 28 wells drilled were small oil producers, the oil production for the year was increased over 4,000 bbl due to secondary recovery.

TABLE 10 - DEVELOPMENT AND PRODUCTION IN SOUTH CENTRAL KENTUCKY DURING 1949 AS COMPARED WITH 1948

COUNTY	NO. WELLS DRILLED		PRODUCING OIL		PRODUCING GAS		DRY		OIL PRODUCED	
	1948	1949	1948	1949	1948	1949	1948	1949	1948	1949
Adair	1	7	0	2	0	0	0	5	0	0
Allen	25	27	20	18	0	0	5	9	52,614	67,682
Barren	7	9	3	0	0	0	4	9	9,691	9,395
Clinton	40	24	34	6	0	0	6	18	430,748	252,030
Cumberland	36	12	20	8	0	0	16	4	11,157	32,646
Lincoln	5	1	0	0	0	0	5	1	0	0
Marion	1	0	0	0	0	0	1	0	0	0
Mc Creary	3	3	0	0	0	0	3	3	1,328	708
Pulaski	12	7	2	0	6	3	4	4	0	0
Russell	11	3	4	0	0	0	7	3	0	5,457
Simpson	0	5	0	0	0	0	0	5	1,046	853
Wayne	12	28	7	8	0	1	5	19	22,261	26,367
Total	152	126	90	42	6	4	56	80	528,845	395,138

Oil And Gas Developments In Missouri During 1949

By FRANK C. GREENE*

Oil and gas development in Missouri in 1949 was not marked by any important discoveries or changes from the trends of previous years. Oil production rose slightly to a total of 32,027.55 bbl, with a value of $54,356.11 and natural gas sold amounted to 23,340 M cu ft with a value of $3,256.76. As nearly as can be determined 99 oil wells were pumped, but were not in continuous daily production. The gas was produced from 11 wells.

Oil is produced in Atchison, Platte, Jackson and Cass counties and the gas from Platte and Clinton counties.

*Geologist, Missouri Geological Survey and Water Resources.

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Manuscript received at the office of the Institute, April, 1950.

Completions in Missouri in 1949

County	Oil	Gas	Dry
Benton			1
Cass	1	3	7
Clinton			3
Jackson	3	2	3
Perry			1
Pettis			1
Platte		1	3
Stoddard			1
Vernon			1
Totals -	4	6	21

The total footage was 15,573 ft, all with cable tools.

Oil And Gas Developments In Nebraska During 1949

By E. C. REED*

The most significant development in Nebraska during 1949 was the discovery of oil in the Gurley Field in Cheyenne County by the Ohio Oil Co. at their Mary Egging No. 1 well, located in the N E 1/4 - N E 1/4 - N E 1/4 of Sec. 11, T. 15 N., R. 49 W. The discovery well was completed at a total depth of 4,429 ft on June 9, 1949 when production tests indicated about 17 bbl per hour of 36 degree A.P.I., greenish brown, paraffine base, dry oil. Production was secured from the upper sandstone of the Dakota Group of sandstones and shales of Cretaceous age, entered at 4,401 ft (sea level elevation - 182 ft).

Continental Tertiary rocks were drilled to a depth of 990 ft where the Cretaceous Pierre shale was entered, he base of the Pierre and top of the Smoky Hill member of the Niobrara formation was reached at 3,634 ft, the Fort Hayes limestone member of the Niobrara formation was drilled from 3,870 to 3,910 ft and the Greenhorn limestone was drilled between 4,150 and 4,178 ft in the discovery well. The producing formation correlates northeastward with the upper part of the Dakota Group in its type locality (northeast Nebraska) and correlates northwestward and westward with the Mowry member of the Graneros shale which is approximately equivalent to the "Muddy" or Newcastle sandstone.

The producing structure is a domal anticline trending from northeast - southwest to east - west complicated by some faulting which seems to cut the pre-Pierre, post-Dakota beds in some of the wells but cannot be traced into the Dakota Group rocks. Indications are that the productive area of the Gurley Field will be comparatively small but that other similar structures exist in the general area. The Gurley Field was discovered as a result of extensive seismograph work by the Ohio Oil Co. At the close of 1949 there were a total of six producing wells in the Gurley Field with a potential production of about 1,000 bbl per day and a total production of 92,149 bbl.

Drilling activity in the state during 1949 increased considerably over 1948, largely as the result of the discovery of the Gurley Field in the southern part of the panhandle part of Nebraska. A total of 29 test wells in seven different counties of the state were completed during the year or drilling at the close of the year. Of this total, 15 were located in Cheyenne County, six in Richardson County, four in Dawes County and single operations in Deuel, Fillmore, Morrill and Scotts Bluff counties. A total of 16 dry holes were drilled, nine producing wells were completed and four wells were drilling at the close of the year. In addition to the six producing wells of the Gurley Field, three producers were completed in the Barada Field in Richardson County which extended the Barada Field to the south.

Oil production in Nebraska during 1949 increased about 35 per cent over 1948 as a result of the discovery of the Gurley Field. Richardson County production declined about 8 per cent during the year. A considerable increase in drilling activity in the state is anticipated for 1950.

*Associate State Geologist, Nebraska Geological Survey, Lincoln, Nebraska.

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TABLE 1 - OIL AND GAS PRODUCTION STATISTICS FOR NEBRASKA IN 1949

LINE NUMBER	FIELD (County)[a]	YEAR OF DISCOVERY	OIL PRODUCTION			NUMBER OF WELLS[c]		WELLS PROD. DEC. 1949 OIL, ARTIFICIAL LIFT	CHARACTER OF OIL[b] GRAVITY A.P.I.	PRODUCING FORMATION					DEEPEST ZONE TESTED[d] TO END OF 1949	
			AREA PROVED ACRES	BARRELS		COMPLETED TO END 1949	COMPLETED 1949			CHARACTER[e]	POROSITY PER CENT	DEPTH TO TOP OF PRODUCING ZONE FT.[f]	PROD. THICKNESS AVG. FT. / NET	STRUCTURE[g]	NAME	DEPTH OF HOLE, FT
				TO END OF 1949	DURING 1949											
1	Barada, *Richardson*	1941	540	1,160,111	84,862	22	3	17	29.6	D	C	2,403	78	A	Arbuckle-Cam-Ord	3,850
2	Dawson, *Richardson*	1940	440	207,930	10,000 x	14		4	21.7	D	C	2,192	29	A	Pre-Cambrian	3,424
3	Falls City, *Richardson*	1939	1,080	4,349,766	102,284	57		33	31.5	D	C	2,250	23	A	Arbuckle	3,372
4	Gurley, *Cheyenne*	1949	120	92,149	92,149	6	6	6	36.1	S	x	4,400	10	A	Morrison-Jurassic	5,026
5	Shubert, *Richardson*	1940	400	124,204		10			29.0	D	C	2,495	23	T	Hunton-Devonian	2,638
	Total		2,580	5,934,160	289,295	109	9	60								

TABLE 2 - SUMMARY OF DRILLING OPERATIONS IN NEBRASKA

IMPORTANT WILDCATS DRILLED IN 1949

LINE NUMBER	COUNTY OR LOCALITY	LOCATION			TOTAL DEPTH, FT OR METERS	FORMATION	DEEPEST HORIZON TESTED	DRILLED BY	INITIAL DAILY PROD. OIL, U. S. BBL	REMARKS
		SEC.	TWP.	RGE.						
1	Cheyenne	C-NE-NW 25	14 N	50 W	4,729	Tertiary-Plio	Cret-Dak. Gp.	Roberts Bros.		D & A
2	Cheyenne	NW-NE-NE 8	14 N	51 W	5,047	Tertiary-Plio	Cret-Dak. Gp.	Lohman, et al		D & A
3	Cheyenne	SW-NW-NE 7	14 N	49 W		Tertiary-Plio		Ohio Oil Co.		Drilling
4	Cheyenne	NW-NW-SE 18	15 N	48 W	4,462	Tertiary-Plio	Cret-Dak. Gp.	Roberts Bros.		D & A
5	Cheyenne	NE-SW-SW 1	15 N	49 W	4,430	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.		D & A
6	Cheyenne	SW-SW-SW 1	15 N	49 W		Tertiary-Plio		Ohio Oil Co.		Drilling
7	Cheyenne	NE-SE-SE 2	15 N	49 W	5,026	Tertiary-Plio	Jurassic-Morrison	Ohio Oil Co.		Dry (salt water disposal)
8	Cheyenne	C-SE-SE 2	15 N	49 W	4,397	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.		Producer-Gurley Field
9	Cheyenne	SW-SW-SE 2	15 N	49 W	4,554	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.	65	Producer-Gurley Field
10	Cheyenne	NE-SE-SW 2	15 N	49 W	4,431	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.		D & A
11	Cheyenne	NE-NE-NE 11	15 N	49 W	4,429	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.	230	Producer-Gurley Field
12	Cheyenne	NE-NW-NE 11	15 N	49 W	4,362	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.	250	Producer-Gurley Field
13	Cheyenne	SW-NW-NE 11	15 N	49 W	4,577	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.	120	Producer-Gurley Field
14	Cheyenne	NE-NW-NE 12	15 N	49 W	4,427	Tertiary-Plio	Cret-Dak. Gp.	Ohio Oil Co.	250	Producer-Gurley Field
15	Cheyenne	NE-NE-SE 20	16 N	49 W	4,615	Tertiary-Plio	Cret-Dak. Gp.	Frontier & Ideal		D & A
16	Dawes	SE-SE 1	29 N	49 W		Tertiary		H. L. Hollingworth		Drilling
17	Dawes	NE-SE 30	30 N	48 W	2,913	Tertiary	Jurassic	M. M. Newell		Drilling
18	Dawes	C-NE 30	35 N	47 W	1,628	Cret-Niobrara	Jurassic	Chadron Oil Co.		D & A
19	Dawes	SE-NE-NW 25	35 N	48 W	2,700	Cret-Pierre	Permian	H. L. Hollingworth		D & A
20	Devel	NE-NE-NW 19	13 N	42 W	3,885	Tertiary	Jurassic-Morrison	Ideal, et al		D & A
21	Fillmore	SE-SW-NW 3	5 N	2 W	3,230	Pleist on Cret	Arbuckle	Fillmore Dev. Co.		D & A
22	Morrill	SE-SE 21	19 N	51 W	4,275	Tertiary	Cret-Dak. Gp.	W. C. Emrich		D & A
23	Richardson	E-SW-NW-NW 1	2 N	16 E	2,475	Pleist on Pen	Dev-Hunton	Monebia Dev. Co.	600	Producer-Barada Field
24	Richardson	W-SW-NW-NW 1	2 N	16 E	2,482	Pleist on Pen	Dev-Hunton	Monebia Dev. Co.	100	Producer-Barada Field
25	Richardson	NE-NE-NE 2	2 N	16 E	2,532	Pleist on Pen	Dev-Hunton	Monebia Dev. Co.	75	Producer-Barada Field
26	Richardson	NE-NW-NE 33	1 N	16 E	2,525	Pleist on Pen	Dev-Hunton	Clayton Ross, et al		D & A
27	Richardson	SE-SE 35	3 N	16 E	2,527	Pleist on Pen	Dev-Hunton	Stout & Hahn		D & A
28	Richardson	SW-SW 36	3 N	16 E	2,549	Pleist on Pen	Dev-Hunton	John Peters		D & A
29	Scotts Bluff	SW-SW-NE 5	21 N	54 W	5,304	Tertiary	Cret-Dak. Gp.	Baxter Drilling Co.		D & A

	IN PROVEN FIELDS	WILDCATS
Number of wells drilling Dec. 31, 1949	1	3
Number of wells completed during 1949	8	2
Number of gas wells completed during 1949	0	0
Number of dry holes completed during 1949	2	14

The Drift of Things

. . . as followed by **EDWARD H. ROBIE**

Secretary AIME

New Oil Bonanza

If one turns to an ordinary atlas and tries to spot a certain county in Texas without the aid of an index he will find the job rather time-consuming for the Lone Star State has 254 such subdivisions, almost 100 more than the next most "countified" state of Georgia. However, in the western part of Texas the map is not too much cluttered up with towns and railroads and other evidences of civilization, so it is not too difficult to find Scurry County. In fact, its county seat, Snyder, stands out as more of a town than its 1940 population of 3,815 would indicate. Lubbock, 80 miles to the northwest, was until a year and a half ago, much better known, but not now, at least among oil men. For Snyder is the center of a new boom, a new oil field that may rival the famous East Texas field. Its population has jumped to 30,000. Living quarters and public utilities are being hastily constructed and some 4,000 trailers offer temporary homes, according to a recent *Wall Street Journal* article.

No one knows how much oil there is underground but there are now some 700 wells producing from a reef formation 6,000-7,000 ft below the surface. Intelligent guesses indicate perhaps a billion and a half barrels of oil, more oil than was found in the first two years of East Texas, and more than has ever been found in Oklahoma, the fourth largest producing state in the Union. The field seems to be crescent-shaped, some 33 miles long at present, from its northeast extremity in Kent County, across Scurry County, to its southwestern end in Borden County. Standard Oil Co. of Texas (Standard of California subsidiary) brought in the first well and now owns perhaps the biggest acreage. Magnolia Petroleum (Socony-Vacuum subsidiary) and Lion Oil are also big holders. A score of other companies are also in the field, and the local Baptist and Methodist churches are putting down holes on their properties. Several of the early wells drilled last year were in relatively widely spaced locations and only recently has it been realized that they were drawing from the same pool. Not enough wells have yet been drilled to determine whether or not *all* of the wells in the area are in the so-called Canyon Reef formation. Some are dry holes.

Discovery of this huge new oil field supports the view of many who have been continuously optimistic about the future of new oil discoveries in this country. With higher prices, more wildcat wells and more footage were drilled last year than ever before, and this is one of the fruits. Naturally, the ground more than a mile below the surface has not been so carefully tested as that more conveniently situated. The Scurry field should give encouragement to those engaged in expensive exploration at great depths.

The Tariff and World Problems

Congressional hearings on a proposal to increase the duty on imported crude petroleum from half a cent a gallon to two cents a gallon, and on other matters of interest to various groups in the mineral industry, have brought all the old familiar arguments about the benefits and evils of tariff protection. As to the oil imports, the small "independent" oil producers and the coal producers are the chief protagonists for increasing the duty. They affirm that imported oil is making cut-throat competition which is driving oil and coal-mining companies out of business. Thousands of coal miners are jobless, the health of their children affected, and "even the public schools are imperiled." Also, the security of the country is threatened, for the supply lines of the imported oil would likely be cut in case of war, and it would take a long time to train miners and get domestic dormant mines back into operation. Much the same arguments, plus the complaint that foreign products afford unfair competition because of low labor costs through the use of slave or peon labor, are offered in arguments for increasing the tariffs on many other things.

On the other side of the fence are those that feel that John L. Lewis, by increasing the cost of mining coal and by strikes which have often made coal impossible to get at any price, has hurt the sale of coal much more than has imported oil. The suggestion has been made that the oil industry should send Mr. Lewis a bouquet of orchids every day.

Willard Thorp, Assistant Secretary of State, in opposing the proposed increased tariff, maintained that coal has lost ground to oil and gas for over 30 years and that the influx of foreign oil — now slightly under a million barrels a day — has had limited, if any, force on this trend. He asserted that oil is a vital part of the country's trade program; it is one of the ways that foreign countries pay for American exports. Security in case of war would be seriously threatened, too, for without an American outlet, foreign oil producers would be weakened, yet we would need their aid.

Neither did Mr. Thorp think that imported oil was harming the domestic oil industry to any extent to worry about, in view of the fact that new records were made in drilling last year.

The current discussion is part of the age-long controversy before Congress as to tariffs, subsidies, and price supports. On one side is the relatively small but insistent group of domestic producers whose welfare is hurt a great deal by free markets and absence of adequate tariff protection. Their investments and jobs may truly be wiped out, and the communities they support may become ghost towns. Protection is a vital matter to them. On the other side are the rest of the citizens of the country, enormously greater in number but comparatively disinterested because a few cents more or less that they pay for a few commodities does not affect them individually to any considerable extent. Only occasionally, such as when the Government buys up potatoes to keep the price up and then wastes them, does any considerable number of the common people protest.

Congress, being made up of all kinds of people, from those who place the business interests of large groups of their constituents first to those who are primarily interested in what is good for the country, or even the world, as a whole, usually winds up by adopting a middle ground.

In recent years there has been more of a tendency in the United States to

break away from a local prosperity or nationalistic economy to the view that what is best for the country as a whole should be adopted. Further, that what is best for the world as a whole may well be best for the United States. This on the theory that peace, generally regarded as a *sine qua non* for the happiness of the country, is best assured by freedom of trade and higher standards of living in all countries. One of the leading spokesmen for this point of view is Sumner H. Slichter, Harvard business economist, whose lead article in the June *Atlantic*, "Our Best Defense," has aroused great interest.

Dr. Slichter points out some of the economic problems that the country must face in the next decade, and how the cold war with Soviet Russia can be handled. The two most important economic adjustments that must occur, he says, are a return of the prices of farm products to a long-term basis of demand and supply, and more equable conditions in our foreign trade. Three major trends must be halted, he believes: the rapid rise in government expenditures, the rapid spread of government intervention in business, and the drop in the influence of businessmen in the community.

Those who are against removal of tariff barriers, or favor increasing them, or who favor artificial prices to support domestic industries, will find little support in the Slichter article. For instance: "Substantial increases in imports of oil, iron ore, copper, lumber, and many foodstuffs would be in the national interest." "I do not assert that all of these regulations of the government are bad — though a few of them, such as the buying of silver, are completely bad, and others, such as the support of prices of farm products, are badly designed." "The discussion of the several problems . . . has indicated again and again the importance of two things: great increases in production and a large rise in imports."

Embarrassment of Riches

Either a greater amount of interesting work has been going on in the field of the AIME which inspires writers to offer summaries of it for publication, or the various Division papers and program committees have been much more active in soliciting such material. In any case, the Institute has been embarrassed by a superfluity of riches in the form of good technical papers, but unfortunately not also in the form of money. Last year 475 technical papers were submitted for *Transactions* publication, compared with 350 in 1948 and an average of 304 in the preceding five years.

In brief, many more papers are available for publication in the last half of 1950 than can be published with the available funds. A restriction in the number to be published, or in the total number of pages they occupy, is therefore in order. Auxiliary publication committees are being urged: (1) To limit acceptances of *Transactions* material strictly to Grade A papers. (2) To urge maximum condensation of papers. (3) To advise Institute headquarters which papers can be postponed for publication in 1951 and which should be published promptly.

Papers are ordinarily written for two purposes: (1) To present at meetings. (2) For publication. Most of those on the technical programs for technical sessions of the Institute are prepared with the idea of publication as well as presentation; practically none are prepared for publication only. ★ ★ ★

Cash Primes Oil Wells

Texas oil producer, Clyde H. Alexander.

"All the oil in Texas," says oil producer Clyde H. Alexander, "can't run your car unless a company can get the cash needed to drill wells.

"That's why we oilmen work along so close with bankers. When it takes a million or more to get oil out of the ground, it's hard to get financing except through a large bank with a lot of capital. Of course, borrowing from banks is no problem if your credit's good. Bankers like to lend. That's their business.

"Incidentally, most people are surprised to find oil experts working for a big New York bank. But Chase National has geologists, engineers, and other specialists in its Petroleum Department. They're the kind of fellows who get out into the oil and gas fields. They're men with practical oil-field experience, and when you deal with their bank you get all their savvy free.

"Yes, sir . . . there's more to oil than just finding it. When you finally get it into your car, the chances are some bank supplied the money that got the crude oil out of the ground."

This is another in a series of workaday stories about people and their banks as told to the . . . . .

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A BRIEF EXAMINATION OF THE MEN NOMINATED TO CONDUCT INSTITUTE AFFAIRS IN 1951

O. B. J. Fraser, Chairman of the Nominating Committee, announced the following nominations for President, Vice-President, and Directors for 1951. As provided in Art. IX, Sec. 2, of the bylaws, 25 members or associate members may sign and transmit to the Secretary's office prior to Sept. 1 "any complete or partial ticket of nominees."

In such instance, a letter ballot will be forwarded to all members in the United States, Canada, and Mexico, tabulating both the official ballot and any supplementary nominations. If no supplementary nominations are thus received, no letter ballot will be printed, and nominees on the official ballot shall be declared duly elected at the meeting of the board of directors or the executive committee in November. Brief biographies of the nominees follows.

For President

Willis McGerald Peirce, member of the AIME since 1927, is Assistant to the General Manager of the Technical Department of the New Jersey Zinc Co. at Palmerton, Pa. He has been with the company since 1920 when he received his M.S. degree from Yale. His B.S. was earned at the University of Illinois. He is well known for his work on zinc and for the research organization he has built up. Peirce was Chairman of the Institute of Metals Division in 1935, IMD lecturer in 1944, served as Director of the AIME from 1937 to 1943, and from 1949 to date, and as Vice-President from 1940 to 1943.

For Vice-President

Joseph Lincoln Gillson became an AIME member in 1923 when he was an Instructor in Mineralogy and Petrography at MIT. He had received his B.S. and M.A. degrees from Northwestern University and his M.S. from MIT, where, by 1928, he was an Associate Professor. The following year he returned to Northwestern as Associate Professor of Economic Geology. In 1930 he joined E. I. du Pont de Nemours & Co., Wilmington, Del. Gillson was Chairman of the Industrial Minerals Division, AIME, in 1947, and was recently Chairman of the AIME Committee on Democratization.

For Vice-President

Michael L. Haider was chairman of the publications committee of the AIME Petroleum Division for several years, chairman of the Petroleum Division in 1945, and active on numerous other committees, is good AIME Vice-Presidential timber. He is Vice-President and General Manager of the Production Dept. of the Imperial Oil Co., Ltd., Toronto, going there about four years ago from the Standard Oil Co. (N.J.). After graduation from Stanford in 1927, he worked for the Portland Cement Co., the Richfield Oil Co., and the Carter Oil Co.

For Director

Thomas Gaunt Moore began his present association with The American Metal Co., New York, in 1935 as Field Engineer in the Mining Dept. Following graduation from Harvard in 1931, he became geologist in charge of the Morococha mine of Cerro de Pasco. After three years in Peru, he returned to the Harvard Graduate School for his Ph.D. which he was awarded in 1936. Moore has been active in New York Section affairs and was Section Chairman in 1948.

For Director

Charles E. Lawall, Assistant Vice-President of coal properties for the Chesapeake & Ohio Railway, Huntington, W. Va., was Chairman of the Coal Division, AIME, in 1940 and, with a membership dating back to 1914, has been active in AIME affairs and a frequent contributor to technical literature. Lawall was made President of West Virginia University in 1939, having been Director of its School of Mines. He had been associated with Pittsburgh Testing Laboratories, New Jersey Zinc Co., Bethlehem Steel Co., and Lehigh University.

For Director

John F. Myers, Superintendent of Concentration for the Tennessee Copper Co., Copperhill, Tenn., is one of those who made the organization the Minerals Beneficiation Division, AIME, a *fait accompli* in 1948, and was its first Chairman. Myers graduated from Colorado School of Mines in 1913 and went to work for the Butte & Superior Copper Co. He was with American Zinc Co. of Tennessee for a year and New Jersey Zinc Co. for 11 years, joining Tennessee Copper in 1926 as Superintendent of Milling.

For Director

Fay W. Libbey, with the Department of Geology and Mineral Industries of the State of Oregon in Portland, made his entrance into the mining field in 1906 as night foreman for the Nipissing Mines Co. in Cobalt, Ont. Two years later he was Superintendent of Vulture Mines Co., Wickenburg, Ariz., going from there to the custom assay office in Phoenix, and then into mine leasing, oil field work, and consulting. He was Chairman of the Oregon Section in 1942.

For Director

Albert C. Rubel, Vice-President of the Union Oil Co. of California, Los Angeles, got his B.S. from the University of Arizona in time to be assayer for Magna Copper for three months before going into the Army in 1917. After separation from the 304th Engineers, he became geologist for the Commonwealth Petroleum Co. and then the Richmond Levering Co. In 1923 he joined Union Oil Co. as a geologist, becoming a Director in 1936.

Personals

J. R. Puckett has been transferred from Duncan, Okla., where he was district petroleum engineer for the Magnolia Petroleum Co., to Kermit, Tex., in the same capacity.

Harold E. Parsons has been transferred from Socony-Vacuum's Colombian operation to the exploration staff in Calgary, Alberta. He will continue in geological work, though in a rather different type than the jungle exploration in which he was for the most part engaged in South America.

Leslie G. Nunn, Jr., has become associated with the applications department of the Central Research Lab., of the General Aniline & Film Corp., in Easton, Pa. He had been with the Carter Oil Co.

Wallace E. Pratt, who was Anthony F. Lucas medalist in 1948, was awarded the Kemp Medal at Columbia University May 4 for "distinguished service in geology."

L. C. Stevens, of the B. P. M., The Hague, Holland, has been transferred to the staff of the Shell Caribbean Petroleum Co., Maracaibo, Venezuela, where he heads the exploitation department.

Thomas E. Covington has been transferred by the Tide Water Associated Oil Co. from Venice, La., to Victoria, Tex., as field engineer.

N. W. Williams has been made reservoir engineer with James A. Lewis Engineering, Evansville, Ind.

Fred M. Springer has been employed by the Magnolia Pipe Line Co. as a mechanic's helper in an engineering training program and is associated with the maintenance and construction department.

Donald H. McLaughlin, president of the AIME and of the Homestake Mining Co., gave the commencement address at the Michigan College of Mining and Technology exercises on June 5. The honorary degree of Doctor of Engineering was conferred on President McLaughlin. On June 9, President McLaughlin delivered the commencement address at the Montana School of Mines and received another honorary doctorate in engineering.

H. S. Wiggin has taken a job with the Mexican Bureau of Minerals, where he is employed by the Mexican Government as a geologist.

H. E. Treichler, Jr. joined the Houston Oil Co. of Texas, as general superintendent of field operations on June 1, 1950. Treichler graduated from the Colorado School of Mines in May, 1940, with the degree of petroleum engineer, and during the past ten years has been associated with The Texas Co. in its field operations. He is an active member of the AIME and of the American Petroleum Institute.

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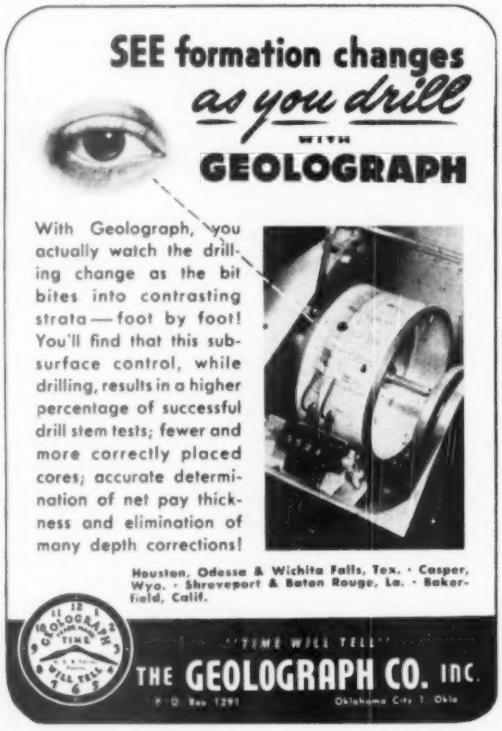
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Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 601 Continental Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened, and no fees are involved.

Replies to the positions coded Y-3429, Y-3059 and Y-2415C below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

POSITIONS

♦ Project Engineer, 30-40, experienced on petroleum and/or gas equipment. Must be able to assume supervision of, and responsibility for, entire section. No recent graduate considered, as position entails immediate responsibility. Location, Pennsylvania. Y-3429.

♦ A principal New York City banking establishment is seeking a graduate in petroleum engineering or petroleum geology, preferably one with several years' experience in field engineering and with some practice in valuation of oil and gas reserves. This position offers experience in oil and gas research studies and property appraisals as well as the correlative advantage of experience in the field of financing and the financial aspects of the petroleum industry. Financial stability and probability of advancement are excellent. Code 521.

♦ Sales Engineer with several years' experience in selling centrifugal process pumps to oil refineries. Salary open, plus commission. Headquarters, New York, N. Y. Y-3059.

♦ Assistant or associate professor with industrial experience in petroleum production engineering, to teach petroleum production courses. Salary open depending on qualifications. Location, South. Y-2415C.

♦ Petroleum engineer or geologist with at least two years' experience, preferably more, for structural geology and evaluation work with sound independent company in New Orleans. Salary commensurate with experience. Code 521.

★ ★ ★

Proposed for Membership
Petroleum Branch

Total AIME memberships on Mar. 31, 1950, was 16,397; in addition 4,037 Student Associates were enrolled.

ADMISSIONS COMMITTEE

E. C. Meagher, Chairman; A. J. Phillips, Vice-Chairman; George B. Carless, John T. Sherman, Lloyd C. Gibson, R. D. Mallison, Plato Malozemoff, Ivan Given.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend its privileges to every person to whom it can be of service but does not desire to admit persons unless they are qualified.

In the following list C/S means change of status; R, reinstatement; M, member; J, Junior Member; AM, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

CALIFORNIA

Bakersfield—Blanchard, Evan Miles (A).
Pico—Johnstone, Donald L. (M).

DISTRICT OF COLUMBIA

Washington—Cox, W. Philip (M). Samathapandhu, Niratana (J).

KANSAS

Independence—Boltacz, John Theodore (J). Reid, Thompson (C/S—S-J).
Wellsville—Capron, Wayne C. (M).

LOUISIANA

Charenton—Lewis, Tom G. (M).
Jennings—Harper, George Marshall, Jr. (J).
Morgan City—Webb, Keith Thompson (C/S—S-J).
New Orleans—Atwater, Gordon Ingham (M).
Ville Platte—Gentry, Arthur Alden (C/S—S-J).

MISSISSIPPI

Natchez—Jones, Oliver Wilson (J).

MONTANA

Billings—Hadley, Herbert David (M).
Harlem—Thompson, Charles Lynn (R,M).

OKLAHOMA

Oklahoma City—Donham, James Franklyn (C/S—S-J).
Tulsa—Rough, Eldred Wilson (M).

PENNSYLVANIA

Shreveport—Miller, Darrell Parry (R,C/S—S-M).

TEXAS

Austin—Sahankaya, Sait (C/S—S-A).
Beaumont—Wiese, Byron, Jr. (C/S—A-M).
Dallas—Elliott, William C., Jr. (J). Priddy, Ashley Horne (C/S—S-J).
Houston—Dick, Melvin L. (M). Luffel, Donald Leroy (J). Pierce, John Edward (J).
Jacinto City—Kerver, John Kingsley (J).
Kamay—McPhail, William H. (J).
Sundown—Lobdell, Seth Lewis (J). Semon, Jack Duane (J).

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Leading oil companies* are taking advantage of these versatile, time-saving determinators. Write to Dept. P-4 for detailed information on how you can apply rapid carbon and sulfur analysis to your problems.

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Book Reviews

PHYSICAL PRINCIPLES OF OIL PRODUCTION

By Morris Muskat, McGraw-Hill Book Co., New York, Toronto, London, 1949. 922 pp., illus., diagrs., charts, maps, tables, 9¼ x 6¼ in., cloth, $15.00.

Reviewed by R. C. Craze, Humble Oil and Refining Co.

The science of oil-reservoir engineering, developed during the past 20 years, has been built on the research of many workers who studied the fundamental nature of oil reservoirs, characteristics of the porous media, properties and behavior of the contained fluids, and the mechanics of flow. In his introduction to *Physical Principles of Oil Production* Muskat points out that "the ultimate goal underlying the development of the science of reservoir engineering is the attainment of a maximum efficiency in the exploitation of oil-bearing reservoirs."

Application of the knowledge acquired during this evolutionary process to production practice has resulted in greater oil recoveries and more efficient field operation. The ultimate goal still offers a challenge and the horizons for further investigation are broad.

This book has as its purpose the formulation and correlation of present-day information concerning the physical principles underlying the mechanics of oil production. It approaches the subject through detailed analyses of the concepts which form the foundation for the interpretation of actual oil field performance. Theoretical background, results of laboratory investigations, and field studies have been integrated into a unified whole. The treatment of the subject combines the author's personal interpretation and knowledge with abundant reference to the published works of many investigators. Such treatment enhances the stature of the work as one of the few books available to the industry which combines in one volume a thorough coverage of the subject and its literature.

The subject is developed in a logical and orderly fashion. The first eight chapters treat first the physical properties and behavior of petroleum fluids, the properties of oil-bearing formations, and secondly, discuss the basic dynamical equations for homogeneous fluid-flow systems and problems relating to well performance and formation properties under such flow. The natural step to heterogeneous fluid flow is then developed. These chapters are preparatory to and the foundation for the remainder of the book which carries the reader into the performance of oil reservoirs. The subject of general reservoir mechanics and classification of producing mechanisms is introduced, together with the material balance equation and its application to reservoir analysis. The behavior of gas drive and water drive reservoirs are then presented in more detail.

Here are discussed the fundamental principles of fluid flow underlying the behavior of reservoirs in these classifications and the application of these fundamentals to techniques of analysis to delineate the performance. The extention of these fundamentals to the interpretation of reservoir performance is carried into secondary recovery operations, water flooding, and gas injection. The recovery of hydrocarbons from condensate reservoirs and cycling operations are also discussed. The final chapter considers the subjects of well spacing and its role in the recovery of oil, interference phenomena, and recovery factors and recoverable reserves. Throughout the book, and particularly in its latter half, actual field and well performance case histories are utilized to advantage to illustrate the subject material and to coordinate the theoretical, experimental and operating aspects.

Viewed in its entirety, Muskat's *Physical Principles of Oil Production* is a worthy and complementary successor to his earlier more highly theoretical *Flow of Homogeneous Fluids Through Porous Media*. It offers to the industry a contribution in the field of reservoir performance which skillfully combines fundamental principles, laboratory investigation, and field application into a composite delineation of reservoir behavior. To the student of reservoir engineering, the production technologist, the field engineer, the research worker, this book is recommended as an addition to his technical library. The material is presented in a manner which is stimulating and thought-provoking and encouraging to further research. Future progress in the art will fill in many of the recognized gaps and require the writing of new chapters on this complex and fascinating subject. ★ ★ ★

DATA BOOK ON HYDROCARBONS — APPLICATION TO PROCESS ENGINEERING

By J. B. Maxwell, D. Van Nostrand Co., Inc., New York, 1950. Charts, nomographs and tables.

Reviewed by Carl S. Kuhn, Jr., et al, Magnolia Petroleum Co.

The author and his associates are to be commended for an excellent and timely compilation of basic data on hydrocarbon fractions and petroleum fractions of special interest to technical personnel in the refining phase of the petroleum industry. For the most part, the data are presented graphically utilizing 176 charts and nine nomographs. In addition, tables are included of the physical constants of hydrocarbons and of the common non-hydrocarbon gases. The material is conveniently classified into 14 principal sections covering Physical Constants, Characteristics of Petroleum Fractions, Molecular Weight, Vapor Pressure, Fugacity, Critical Properties, Thermal Properties, Density, Viscosity, Combustion, Flow of Fluids, Flow of Heat, Equilibrium Flash Vaporization, and Fractionating Towers. Appropriate but brief introductory comments, examples, and references are given in each of these sections.

Although much of the material will be useful to people engaged in reservoir engineering and in cycling or natural gasoline plant design and operation, the data is not generally applicable to calculations at the high pressures normally experienced in these phases of petroleum engineering. The fugacity data, particularly, is not adequate for extensive calculations on high pressure reservoir problems. In addition, the fugacity data could be more conveniently used for many purposes if it were expressed in terms of equilibrium constants. Data on the explosive limits of hydrocarbons and values of gallons/mol could have been included for convenience in the table of hydrocarbon physical constants, but these are minor omissions in an otherwise well written data book. ★ ★ ★

Two new books at a special price to AIME members

PHYSICAL PRINCIPLES OF OIL PRODUCTION

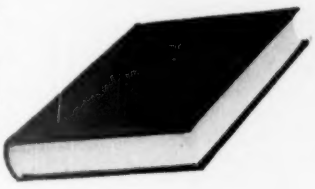
By MORRIS MUSKAT

Director of Physics Division, Gulf Research and Development Co.

937 pages, 352 graphs, diagrams, etc., 50 tables.

Here's the key to greater efficiency in oil and gas production . . . provided in authoritative explanations of the physical principles involved in reservoir engineering and their application in actual field practice.

This reference presents the fundamentals of physics that underlie all basic types of oil-production mechanisms, including the solution-gas-drive, water-drive, and gravity-drainage systems. It also discusses in detail the development of condensate reservoirs, and the recovery of additional oil from depleted reservoirs by both gas and water injection. See a review of this book on page facing this advertisement.



A few of the many topics explained in this book:

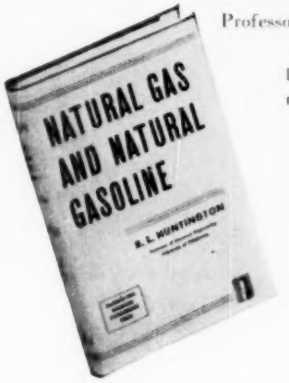
- anisotropic formations
- bottom-water drives
- bulk-volume determinations
- calculation of recoverable reserves
- condensate reservoir development
- core analysis

NATURAL GAS AND NATURAL GASOLINE

By R. L. HUNTINGTON

Professor of Chemical Engineering, University of Oklahoma

598 pages, 6 x 9, illustrated



Latest methods in the production and transportation of natural gas and natural gasoline

Here is a book which covers the production of natural gas from crude-oil, condensate, and dry-gas fields, and the manufacture of liquefied products from this raw material. The recovery of natural gasoline, as well as its transportation and storage, is discussed, and the design and operation of gas gathering and natural gas recovery systems are clearly treated.

This book gives answers for problems concerning the location and design of natural gas plants, the estimation of gas and gasoline reserves, and the construction and operation of pipe lines. It covers distillation and fractionation, gas dehydration, oil absorption, gas condensate cycling, and the latest operational advances in the industry. This book was reviewed in JOURNAL OF PETROLEUM TECHNOLOGY for June, 1950.

As a special service to AIME members only, the Petroleum Branch of AIME offers each of these books at a special discount rate. *NATURAL GAS AND GASOLINE*, which the publisher sells for $8.00, can be ordered through this magazine for $6.50. *PHYSICAL PRINCIPLES OF OIL PRODUCTION*, normally $15.00, can be ordered for $12.00.

Send your order only to Petroleum Branch of AIME in Dallas. Order *must* be accompanied by check and a signed copy of the coupon on this page.

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Please send me _____ copy (copies) of *Physical Principles of Oil Production*, by Morris Muskat
_____ copy (copies) of *Natural Gas and Natural Gasoline*, by R. L. Huntington

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(Signed) _____

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United Geophysical Co. *Dozier-Graham-Eastman, Los Angeles, Calif.*	*

* In previous issues

PETROLEUM BRANCH MEETING CALENDAR

JULY Through DECEMBER

JULY

18	Gulf Coast Section
20	South Plains Sub-Section
21	Mississippi Sub-Section
24	Pacific Petroleum Chapter

AUGUST

10	Pacific Junior Group
17	South Plains Sub-Section
28	Pacific Petroleum Chapter

SEPTEMBER

7	Illinois Basin Chapter
11	Mid-Continent Section
12	Delta Section
13	Southwest Texas Section
14	Pacific Junior Group
19	Gulf Coast Section
20	Kansas Section
21	South Plains Sub-Section
21	Oklahoma City Section
22	Mississippi Sub-Section
25	Pacific Petroleum Chapter
25	Permian Basin

OCTOBER

4-6	**Petroleum Branch, AIME, New Orleans**
5	Illinois Basin Chapter
9	Mid-Continent Section
9-13	Mineral Economics Division, Washington, D. C.
11	Southwest Texas Section
12-13	**Petroleum Branch, AIME, Los Angeles**
17	Gulf Coast Section
18	Kansas Section
19	South Plains Sub-Section
19	Oklahoma City Section
23	Pacific Petroleum Chapter
30	Permian Basin

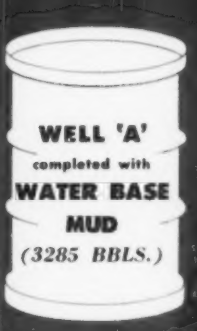
NOVEMBER

2	Illinois Basin Chapter
8	Southwest Texas Section
13	Mid-Continent Section
14	Delta Section
15	Kansas Section
16	South Plains Sub-Section
16	Oklahoma City Section
21	Gulf Coast Section
27	Pacific Petroleum Chapter
27	Permian Basin Section

DECEMBER

1	Mississippi Sub-Section
7	Illinois Basin Chapter
11	Mid-Continent Section
12	Gulf Coast Section
12	Delta Section
14	Pacific Junior Group
20	Kansas Section
21	South Plains Sub-Section
21	Oklahoma City Section

2590
extra barrels every month for 6½ years



NOTE THE SIMILARITY OF THESE OFFSET WELLS

	WELL A	WELL B
Sand Thickness	**180 ft.**	**190 ft.**
Average Sand Permeability	**115 md.**	**105 md.**
Static Pressure	**3135 psi**	**3100 psi**
Millidarcy feet of sand	**20,700**	**19,950**

*The oil base mud used in this well contained air-blown asphalt and was mixed with a refined type oil. After several improvements this mud became known as Black Magic.

BLACK MAGIC ASSURES MAXIMUM RECOVERY

OIL BASE, INC., 130 Oris Street, Compton, Calif.

CORE LABORATORIES, INC., Dallas, Texas

CORE

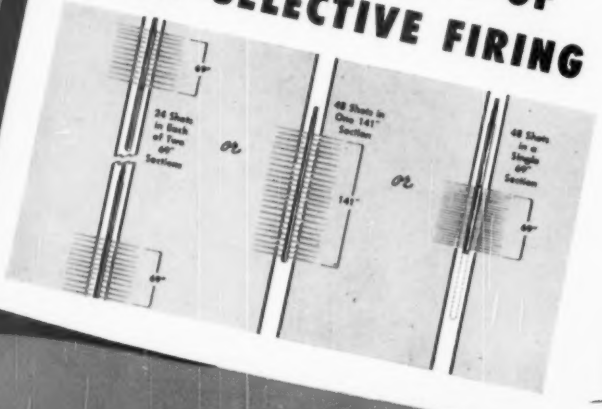
LANE-WELLS F-2 GUN

GIVES YOU BOTH AT ONCE!

THE DEEP PENETRATION
OF
KONESHOT
SHAPED CHARGE
PERFORATING

AND

THE FLEXIBILITY OF
SEMI-SELECTIVE FIRING



Ask Your Lane-Wells Man!

LANE WELLS

TECHNICAL OILFIELD SERVICES

LOS ANGELES • HOUSTON • OKLAHOMA CITY

General Offices, Export Office and Plant
5610 SO. SOTO STREET, LOS ANGELES 11, CALIFORNIA

LANE-WELLS CANADIAN COMPANY

PETRO-TECH SERVICE CO. IN VENEZUELA

AK-304